# HANDBOOK

FOR

# MECHANICAL ENGINEERS

Henry Adams

# HANDBOOK

FOR

# MECHANICAL ENGINEERS



BY

HENRY ADAMS

PROFESSOR OF ENGINEERING AT THE CITY OF LONDON COLLEGE;
MEMB. INST. MECHANICAL ENGINEERS; MEMB. INST. CIVIL ENGINEERS;
PAST PRESIDENT SOCIETY OF ENGINEERS, ETC.

FOURTH EDITION

*REVISED AND FURTHER ENLARGED, WITH COPIOUS INDEX*

London:
E. & F. N. SPON, LIMITED, 125 STRAND
New York:
SPON & CHAMBERLAIN, 12 CORTLANDT STREET
1897

# PREFACE.

THIS Handbook is now so well established in the favour of the rising generation of Mechanical Engineers, that, in responding to the call for a new edition, the author has again revised the whole and added much new matter. In dealing with a subject of such magnitude there must of necessity be many omissions, but it is hoped that the notes will be found to contain all the more important definitions and formulæ of which some knowledge is required in examinations and general practice.

60 QUEEN VICTORIA STREET,
LONDON, E.C.

*January* 1897.

# EXTRACTS

## FROM FORMER PREFACES.

The present work . . . is not intended in any way to supersede the ordinary text-books, but simply to supplement them in the form of a student's own notes, which should represent a summary of his reading and study. The notes are compiled from various sources; in many cases the authority is given, in others the information is original, or has been derived from sources of which no record has been kept.—*First Edition*, 1883.

. . . Busy men must have facts and opinions put before them as briefly as possible, and therefore no apology is requisite for giving the information in as condensed a form as is compatible with accuracy.—*Second Edition*, 1890.

. . . When various formulæ are given for the same thing, they are placed as nearly as possible in chronological order (e.g. N.H.P., p. 240), so that generally, but not always, the last will represent the best and most recent practice. In some cases, where there is no recognised standard, the various formulæ given are all in actual use, and therefore represent general practice; the engineer must in these cases make his own selection.—*Third Edition*, 1893.

# CONTENTS.

# INDEX TO SUBJECTS.

## SECTION I.

### FUNDAMENTAL PRINCIPLES.

## SECTION II.

### VARIETIES AND PROPERTIES OF MATERIALS.

## SECTION III.

### STRENGTH OF MATERIALS AND STRUCTURES.

## SECTION IV.

### PATTERN-MAKING, MOULDING AND FOUNDING.



## SECTION V.

### FORGING, WELDING, RIVETING, ETC.

## SECTION VI.

### WORKSHOP TOOLS AND GENERAL MACHINERY.

## SECTION VII.

POWER TRANSMISSION BY BELTS, ROPES, CHAINS AND GEARING.

## SECTION VIII.

### FRICTION AND LUBRICATION.



## SECTION IX.

### THERMODYNAMICS, AND STEAM.

## SECTION X.

### STEAM BOILERS.

## SECTION XI.

### THE STEAM ENGINE.

## SECTION XII.

### HYDRAULIC MACHINERY.

## SECTION XIII.

### ELECTRICAL ENGINEERING.



## SECTION XIV.

### SUNDRY NOTES AND TABLES.

## APPENDIX I.

### Syllabus of City and Guilds of London Institute.

## APPENDIX II.

SYLLABUS OF GOVERNMENT DEPARTMENT OF SCIENCE AND ART.



## APPENDIX III.



---

GENERAL INDEX AT END OF BOOK.

---

# HANDBOOK

FOR

# MECHANICAL ENGINEERS.

## SECTION I.

## FUNDAMENTAL PRINCIPLES.

### 1. Induction and Deduction.

The process of *induction* is a logical system of forming conclusions *from the special to the general*, by which we advance from many individual experiences to a general law; *deduction*, on the other hand, draws a conclusion *from the general to the special*, from a general law of nature to an individual case. —*Haeckel.*

### 2. Force, Matter and Motion.

*Motion* is change of place. Intensity of motion is called velocity.

*Velocity* is motion considered in relation to time.

*Force* is that which produces or destroys motion, or which tends to produce or destroy it; or which alters or tends to alter its direction.

*Matter* is that which is the subject of motion or a tendency to motion. It is the element of resistance in the sensible world.

"Force and matter are correlates, inconceivable apart, they necessarily involve acceptance of space and time."

—*Stallo's Concepts.*

If one force only acts upon a body, motion must ensue. Forces in equilibrium are called pressures or reactions. Pressures and resistances are the active and passive states of force; in whatever direction they are exerted they may be measured in lbs., and when exerted through any given space may be measured in foot-lbs. Force may be measured by the pressure it produces upon some obstacle, and compared with gravity, or by the motion which it produces in a body in a given time. Motion may be uniform or variable: uniform motion is when a body continues to pass over equal spaces in equal times; variable motion may be uniformly accelerated, uniformly retarded, or irregular.

*Philosophically, Matter and Force (Substance and Accident) are known as Mass and Motion, and the ultimate inseparables of Mass, Form and Motion together constitute Matter or the Reality of Things.*

### 3. Indestructibility of Matter, or Conservation of Mass.

Matter is indestructible. The atoms composing it may enter into new combinations, or may be subjected to new conditions, but no variation can be made in the absolute quantity of matter in the universe.

### 4. Particles, Molecules and Atoms.

*Particles* are the smallest visible or tangible portions of the mass.

*Molecules* are the smallest physical portions of matter retaining the properties of the bulk.

*Atoms* are the ultimate indivisible portions of matter, probably spherical and less than the one-hundred-millionth of an inch in diameter. Cauchy defined atoms as "material points without extension."

Molecules are the ultimate products of the physical division of matter, atoms the ultimate products of its chemical decomposition.

Dr. Paul Carus suggests that the world-substance consists of minute units (possessing a continuity which places them in constant relation to each other) and in its simplest form identical with what physicists call ether; two or more ether monads forming what we call an atom, various combinations of ether-monads forming the various elementary atoms.

*Polarity* is believed to be inherent in every atom of the universe, material or immaterial.

### 5. Chemical Elements.

Substances which, after subjection to all methods of analysis at present known, are not separable into two or more components, are known as chemical elements. There are at the present time about seventy acknowledged elements, and two or three doubtful ones.

### 6. Chemical Compounds.

$H_2O$, as the chemical symbol for water, means that it consists of two volumes of the gas hydrogen combined with one volume (at the same temperature and pressure) of the gas oxygen. By weight, however, the proportion is 2 of hydrogen to 16 of oxygen, their atomic weights being $H = 1$, $O = 16$, or in other words, oxygen weighs sixteen times as much as an equal bulk of hydrogen.

In chemically compound substances a molecule must consist of atoms of all the component elements of the substance, in their proper relative proportions. In chemically simple substances the atoms probably exist in combination as molecules, various combinations producing the phenomena of allotropism, isomorphism, isomerism, &c.

*Allotropic* substances are those which exist under more

than one form ; the most striking example is carbon, which occurs as diamond, graphite, charcoal and lamp-black.

*Isomeric* substances are composed of the same elements in the same proportions, but exhibit different properties.

*Isomorphous* substances are those having the same crystalline form and analogous chemical composition.

*Dimorphism*, as when a substance crystallises in either of two different orders of crystals, is a form of allotropy.

*Amorphous* substances are those which have an indefinite form, as pitch, &c.

## 7. Solids, Liquids and Gases.

In solids the molecules are relatively fixed, in liquids they are coherent but not fixed, in gases they are repellent to each other. Hence solids press downwards only, liquids press downwards and sideways, gases press in all directions.

The pressures are the effects of gravity only, when the substances are unconfined.

## 8. Molar and Molecular Motion.

*Molar motion* is the motion of masses in contradistinction to the motion of molecules. It expresses the motion of a body as a whole.

*Molecular motion.* The molecules of all bodies are in a state of continual agitation. The hotter a body is the more violently are its molecules agitated.

In solids the path described by a given molecule is limited and confined to a very small space.

In liquids a molecule is unlimited in its motion and may penetrate to any part of the space occupied by the liquid.

In gases the molecules move with great velocity in straight lines, and in all directions. They therefore diffuse rapidly, the lighter gases more so than the heavier.

—*Clerk Maxwell.*

## 9. Attraction of Cohesion and Adhesion.

*Attraction of cohesion* is the molecular attraction between the particles of the same body.

*Attraction of adhesion* is the physical attraction of the particles of dissimilar bodies in opposition to the force of cohesion.

*Capillary attraction* is a form of adhesion, and the term capillarity includes all effects depending upon the adhesion or repulsion between fluids and solids.

## 10. Newton's Law of Universal Gravitation.

All bodies whatever attract each other with a force proportional directly to their masses and inversely to the squares of the distances between them. "The reason of these properties of gravity," he said, "I have not as yet been able to deduce; and I frame no hypotheses."

By some writers this statement is divided into two laws of gravitation, thus—

*First law.* Every body or substance in the universe attracts every other body with a force proportionate to its mass.

*Second law.* Bodies attract each other inversely as the square of the distance between them.

## 11. Force of Gravity.

*Gravity*, or the attraction one body has for another, being proportional to the mass of the body, that of the earth practically overwhelms all others. The direction of attraction is towards the centre of the mass, hence, under the action of gravity, all bodies tend to fall towards the centre of the earth.

*Accelerating Force of Gravity*, or *Acceleratrix of Gravity*, is

the velocity imparted to bodies falling near the surface of the earth, in lat. 45° = 32·17 feet per second, say 32·2 = $g$.

| | |
|---|---|
| Paris . . . | lat. 48° 50′ = 32·1819 |
| Greenwich . . | „ 51° 29′ = 32·1912 |

## 12. Density, Mass and Weight.

*Density* is the quantity of matter, or units of mass, in a unit of volume.

*Mass* is the quantity of matter in a body of any volume, and is constant at all heights and in all latitudes = density × magnitude.

Masses of different substances are equal when the same force acting upon them for the same time produces the same velocity.

*Weight* is the mass × force of gravity, which is only constant at the same level and same latitude, ∴ $W \propto m\,g$, and $m = \dfrac{W}{g}$. The weight is proportional to the mass, but varies inversely as the square of the distance from the earth's centre. The weight of a body is the resultant of its gravity towards all other bodies of the universe compounded with its centrifugal force.

Mass is independent of weight. A body carried from the equator to a pole remains unchanged as to mass, but gains $\frac{1}{2}$ per cent. as to weight.

A body weighs at sea-level, $\frac{1}{295}$ less at the equator than in London; due partly to centrifugal force, and partly to difference in distance from centre of gravity of the earth, i.e. its centre.

A body weighing 200 lbs. at equator weighs 201 lbs. at poles; $\frac{1}{3}$ of this increase is due to shorter radius to centre of earth, and remainder due to absence of centrifugal force.

The effect of centrifugal force at the equator is $\frac{1}{289}$ of the attraction of gravity.

The French use the word *poids* as meaning the quantity

weighed out in a balance, and *pesanteur* as the force of the attraction of the earth on this quantity. The English use the word weight for both.

### 13. Plumb Line.

A plumb line is supposed to hang vertically, i.e. to point to the earth's centre, but owing to the centrifugal force caused by the earth's rotation a plumb line in the latitude of London deviates southward by $\frac{1}{594}$ of its length.

—*Tomlinson's 'Mechanics.'*

### 14. Specific Gravity

of a body is the ratio of its density to that of some standard substance, generally water or air.

The standard for solids is pure distilled water at 60° F., weighing 1000 oz. per cub. foot = $62\frac{1}{2}$ lbs.

The standard for gases and vapours is atmospheric air at 60° F., 30 inches bar., weighing 31 grains per 100 cub. inches = ·07 lbs. per cub. foot.

$W$ = weight of substance in air.
$W_1$ = " " water.
$V$ = volume "
$S$ = specific gravity of substance.
$w$ = weight of unit of standard.

$$W = V S w. \qquad S = \frac{W}{V w}. \qquad S = \frac{W}{W - W_1}.$$

### 15. Units of Force.

*A poundal, absolute unit of force, British kinetic unit*, or *Gaussian unit*, is that force which acting for unit time would impart unit velocity to unit mass. If 1 lb. = unit mass, 1 second = unit time, 1 foot per second = unit velocity, then force in poundals = pressure of $\frac{1}{g}$ lb.

The *metrical absolute unit of force* is the force that, acting on the mass of one cubic centimetre of water at maximum density, 4° C. (mass of gramme) for one second, generates in it a velocity of one centimetre. This is also called the *dyne,* or *metrical kinetic unit.*

British gravitation units of force, or lbs., $\div$ 32 = British absolute units of force, or poundals.

The foot-second-pound system of gravitation units is used by engineers; the C.G.S. or centimetre-gramme-second, or metric system, by physicists and mathematicians. See also par. 688.

### 16. Work and Energy.

*Work* may be defined as a continued motion accompanied by a continuous pressure, = weight $\times$ space passed through vertically; or pressure exerted $\times$ space passed through in any direction. Briefly, *Work* is done when *Resistance* is overcome.

*A unit of work*, U, is the power expended when a pressure of 1 lb. is exerted through a space of 1 foot = 1 foot-lb. The amount of work performed in overcoming a given resistance through a given space is independent of the time occupied.

*A horse-power* (Jas. Watt) is the exertion of 33,000 units of work or foot-lbs. in the period of 1 minute.

*Energy* (Dr. Young) in mechanics means capacity for performing work, and is measured in foot-lbs.

*Potential energy* (Rankine), *Statical energy* (Thomson), *Sum of the tensions* (Helmholtz), or *Positional energy*, is the product of the effort or pressure into the distance through which it is capable of acting.

*Actual energy* (Rankine), *Kinetic energy* (Thomson and Tait), *Dynamic energy* (Tyndall), or *Accumulated work* of a moving body, is the product of the mass of the body into half the square of its velocity, or the weight of the body into the height from which it must fall to acquire its actual velocity. $U = \frac{1}{2} m v^2 = \frac{W v^2}{2 g}$.

*Work done* in raising a body of materials (as in building a house) = work done in raising whole weight to height of centre of gravity.

### 17. Vis Viva and Inertia.

*Vis viva* (Leibnitz), or *Energy of motion* of a moving body, is the product of the mass of the body into the square of its velocity, or double the actual energy $= m\,v^2 = \frac{W\,v^2}{g}$, the units of work being $= \frac{W\,v^2}{2\,g}$.

The vis viva of a body measures the whole effect which will be produced before the velocity is destroyed, thus the penetration of bullets will vary as $m\,v^2$. *Work* depends upon the principle of vis viva, but to compare with other units the unit of work is made $\frac{1}{2}\,m\,v^2$.

*Inertia*, sometimes called *vis inertiæ* or force of inactivity, implies the absolute passiveness of matter, or a perfect indifference to rest or motion, i.e. any change of state must arise from the action of external force.

### 18. Convertibility of Energy.

All forms of energy (as light, heat and mechanical work) are mutually convertible. They are " modes of motion," and consist of *waves*, the direction of displacement of each vibrating particle varying in each case. Actual energy of any form being once existent cannot be annihilated; it can only be transferred into some other form, or to some other matter.

### 19. Conservation of Energy.

The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of these bodies, though it may be transformed into any of the forms of which energy is susceptible.
—*Clerk Maxwell.*

The sum total of energy in the universe is constant. Descartes' doctrine that "the quantity of motion conserved in the world is always the same," took account of one constituent only of energy, and was therefore imperfect.

—*F. Mohr and J. R. Mayer.*

### 20. Inertia and Momentum.

As understood by practical engineers, *Inertia* is resistance to communication of motion, *Momentum* is resistance to extinction of motion. They are equal to each other, and of opposite character.

They are compared with *Work* by ascertaining $h$ necessary to create the $v$ under action of $g$, and considering W as moved through $h$, giving result in foot-lbs.

$$= \frac{W v^2}{2g}, \text{ or } W h, \text{ since } h = \frac{v^2}{2g}.$$

In calculating the power exerted in moving a load, as a truck on a railway, we have the inertia overcome in reaching the velocity attained $\left(\frac{W v^2}{2g}\right)$ added to work done transporting the load through the space passed over ($W \mu s$).

In coming to rest the inertia is given up again as momentum. The value of the momentum is irrespective of the distance in which the velocity was acquired; its effect depends entirely upon the distance in which it is expended.

### 21. Galileo's Law of Inertia.

A material point, when once set in motion, free from the action of an extraneous force and wholly left to itself, continues to move in a straight line so as to describe equal spaces in equal times. This is also Newton's "First Law of Motion."

## 22. D'Alembert's Principle.

"In whatever manner several bodies change their actual motions, if we conceive that the motion which each body would have in the succeeding instant, if it were quite free, is decomposed into two others, of which one is the motion which it really takes in consequence of their mutual actions, the second must be such that if each body were impelled by this force alone (that is, by the force which would produce this second motion), all the bodies would remain in equilibrio."

This is evident; for if these second constituent forces are not such as would put the system in equilibrio, the other constituent motions could not be those which the bodies really take in consequence of their mutual action, but would be changed by the first. —*Gregory's 'Mechanics.'*

## 23. Momentum.

Pressure ($f$) applied to a body of given mass ($m$) free to move, and continued for some definite time ($t$), causes motion at a certain velocity ($v$).

$$v \propto f\,t, \qquad f\,t = m\,v, \qquad f\,t = \frac{W\,v}{g}, \qquad f = \frac{W\,v}{g\,t},$$

or the effect varies inversely as the time occupied, and directly as the mass or weight moved and the velocity of movement.

When the body is already moving with velocity ($v$) and it is increased to ($v_1$), then

$$f\,t = m\,v_1 - m\,v. \qquad\qquad s = \tfrac{1}{2}(v + v_1)\,t.$$

*Momentum* or *Quantity of motion* (Descartes, Newton) = mass × velocity, and represents the constant force which acting for one second would stop a moving body $= m\,v$. A mass in motion, having momentum $= m\,v$, will, after impact with mass $m^1$ at rest, have a resulting velocity of $v^1 = \frac{m\,v}{m + m^1}$, or $m\,v = (m + m^1)\,v^1$.

*Moving force*, or the *Moving quantity of a force*, is the momentum generated in one second.

The term momentum has been applied indifferently to express the quantity of motion existing in a body and its striking force or power of overcoming resistance, but the latter is more properly denoted by *vis viva*.

*Momentum* varies as the velocity, and is the measure of a given force *during a given time of action.*

*Vis viva* varies as the square of the velocity, and is the measure of the force *acting through a given distance.*

In its technical (workshop) use the term momentum signifies the same as actual energy or accumulated work, and is independent of time.

$$\text{Energy} = \frac{m\,v^2}{2} = f\,s. \qquad \text{Impulse} = m\,v = f\,t.$$

$$\text{Average force} = \frac{\frac{m\,v^2}{2}}{s} = \frac{m\,v}{t}.$$

In old books on mechanics "the duplicate ratio of the velocity" means $v^2$.

Two unequal balls with velocities inversely as their masses will have equal momenta, and the same power to overturn an obstacle, but the swifter ball will penetrate a soft body further than the other, or do more *work*. They will both overcome the *same resistance in the same time*, but to have equal piercing effects their masses must be inversely as the squares of their velocities, so that their momentum × velocity may be equal.

## 24. Modern Notation in Dynamics.

Velocity is *time-rate of displacement*. The SECOND is taken as the unit interval [of time] and the FOOT as the unit distance. Velocity is measured in feet displacement per second, the unit of which is a displacement of 1 foot in 1 second, and this unit velocity is called a VELO. Every velocity requires an interval of time in which to produce a finite displacement however small.

When velocity is uniformly increasing, acceleration is measured by the increased velocity in feet-per-second per second, the unit acceleration is an increased velocity of 1 foot per second in 1 second, or 1 velo per second; this unit is called a CELO.

The quantity of matter in any body is called its mass, the unit mass is a pound or 1 lb. Force applied to mass produces acceleration in the direction of the force, the unit force is that force, which acting upon 1 lb. produces 1 celo, and is called a POUNDAL. The force which produces $a$ celos in $m$ lbs. is $m\,a$ poundals, and a mass of $m$ lbs. with $a$ celos has a MASS-ACCELERATION of $m\,a$ POUND-CELOS. The acceleration of any mass due to gravity ($g$) is $32\cdot2$ pound-celos, hence a weight of 1 lb. $= 32\cdot2$ poundals, or a weight of $m$ lbs. is a force of $m\,g$ poundals.

The MASS-VELOCITY or MOMENTUM of a body is the product of the number of lbs. in the body by the number of velos it has. A body of 1 lb. has unit mass-velocity when it has one velo; it is then said to have a POUND-VELO.

A force acting for a definite interval produces mass-velocity and is called an IMPULSE; the unit impulse is that which acting on 1 lb. produces in it 1 velo, and is called a PULSE. It has the same effect as 1 poundal acting for 1 second in producing 1 pound-velo. A pulse might be called a poundal-second.

In units of work 1 foot-pound $= g$ foot-poundals.

## 25. LAWS OF MOTION.

Generally known as "Newton's Laws of Motion."

$$\text{Summary}\begin{cases}\text{I. Change of state is due to external force.}\\ \text{II. Every force produces its own result.}\\ \text{III. Action and reaction are equal.}\end{cases}$$

FIRST LAW OF MOTION (Kepler, also ascribed to Galileo). All motion is naturally rectilinear and uniform. A body at rest will continue at rest, and if in motion will continue

to move in a straight line with uniform velocity, unless acted upon by some external force.

SECOND LAW OF MOTION (Galileo). If a body be acted upon by two or more forces for a given time, the effect will be the same as if the forces acted independently for the same length of time. This is the foundation of the parallelogram of forces.

THIRD LAW OF MOTION (Newton). Action and reaction are always equal and contrary in direction. When a body receives motion from another, the second body loses a quantity of motion equal to that which the first receives. When a pressure produces motion, the quantity of motion, or momentum generated in a given time, is proportional to the pressure.

### 26. EQUILIBRIUM.

May be stable, unstable, indifferent, or mixed.

When a body is resting on another, in such a position that its centre of gravity is the lowest possible, it is in stable equilibrium: e.g. when vertically under the point upon which it is supported. When the highest possible, it is in unstable equilibrium: e.g. when vertically over point of support. When constant for any position, the equilibrium is indifferent or neutral: e.g. a sphere. When stable with regard to movement in one direction, and unstable or indifferent with regard to another direction, it is said to be in a position of mixed equilibrium: e.g. a cylinder lying on its side.

### 27. CENTRE OF GRAVITY

is that point in a body through which the resultant of the gravities (or weights) of its parts passes, in every position the body can assume.

The centre of gravity of two weights, or areas, A, B, placed $l$ distance apart, will be $x$ distance from A when

$$x = \frac{B}{A + B} l.$$

The centre of gravity $x$ of a number of bodies in a straight line with regard to any point A at one end of line, W being the weight, and $y$ the distance of W from A,

$$\text{A}\, x = \frac{\text{W}\, y + \text{W}_1\, y_1 + \text{W}_2\, y_2 + \&\text{c.}}{\text{W} + \text{W}_1 + \text{W}_2 + \&\text{c.}}$$

Bodies in same plane but not in same line must be referred to co-ordinate axes. Bodies not in same plane must be referred to co-ordinate planes.

The centre of gravity is not necessarily situated in the solid portion of a body, or enclosed by its surfaces, it is simply the mean central point of the mass.

## 28. Centroid, or Centre of Gravity of Form.

*Triangle.* Bisect two sides, draw to opposite angles, intersection = c.g.

*Trapezium.* Divide into two triangles, find c.g. of each and join them. Divide into two triangles in the other direction, find c.g. of each and join them. Intersection of c.g. lines = mean c.g.

*Tapered Girder Web.*

$t$ = thickness top,
$b$ = „ bottom,
$h$ = height.

$$\text{Height of c.g.} = \tfrac{1}{3}\, h \left(\frac{2\,t + b}{t + b}\right).$$

*Retaining Wall*, vertical back.

$$\text{Height of c.g.} = \tfrac{1}{3}\, h \left(1 + \frac{t}{t + b}\right).$$

$$\text{Distance of c.g. from face to foot} = \frac{2\,b}{3} - \frac{t^2}{3\,(t + b)}.$$

*Tee-Iron* ⊥. $a$ = area lower part.
A = „ upper „
$d$ = total depth.
$t$ = thickness.

$$\text{Height of c.g. from lower edge} = \tfrac{1}{2}\left(d + t - \frac{a\, d}{\text{A} + a}\right).$$

### 29. Centre of Gravity of Regular Solids.

| | |
|---|---|
| Pyramid . . . . | $= \frac{1}{4}$ height from base. |
| Cone . . . . . | $= \frac{1}{4}$ „ „ |
| Paraboloid . . . | $= \frac{1}{3}$ „ „ |
| Hemisphere . . . | $= \frac{3}{8}$ „ „ |
| Hemispheroid . . | $= \frac{3}{8}$ „ „ |
| Semicylinder . . . | $= \cdot 4244$ of its radius from axis. |
| Segment of disc or of cylinder . . | $= \frac{\text{chord}^3}{12\ \text{area}} =$ distance „ |
| Sector of do. . . . | $= \frac{2}{3}\ \frac{\text{chord} \times \text{radius}}{\text{arc}} =$ do. |

### 30. Centrobaryc Theorem (Tomlinson).

The volume of a "solid of revolution" is equal to the area of its generating plane × the circumference described by the centroid of this plane during revolution. In other words,

$a$ = area of semi-section parallel with axis;
$r$ = radius or distance of c.g. of semi-section from axis;

$$\text{Then contents} = 2\,\pi\,r\,a.$$

This may be used in finding the weight of iron vases, caps and bases of columns, oval counterweights, &c., when great accuracy is desired.

### 31. Centrifugal and Centripetal Force.

A body in motion resists any force tending to make it deviate from a straight line. When the body is rotating, the particles are constrained to move in circular paths. The inertia of the mass resists this constraint and produces tension acting outwards from the centre of rotation. The inertia is in this case called centrifugal force, and the tension centripetal force.

### 32. Centrifugal Force

is the amount required to restrain a body, or part of a body, travelling in a circle, from flying off at a tangent, and is perpendicular to the curve or tangent at each point.

The centrifugal force varies as the square of the angular velocity into the radius of the centre of gravity of the section on one side of axis.

Centrifugal force in absolute units $= m\,v^2/r$, in gravitation units $= \mathrm{W}\,v^2/g\,r$.

Centrifugal force from the earth's rotation acts in opposition to gravity at the equator, and diminishes towards the poles, where it is entirely absent.

### 33. Centre of Gyration

is that point in a revolving body, at which, if the whole mass were collected, the accumulated work per revolution would remain the same. It is also such that the same angular velocity would be generated in the same time by a given force at any place as would be generated by the same force acting similarly on the body itself. It is measured from the centre of revolution and gives the "radius of gyration."

| | |
|---|---|
| Circular wheel, uniform thickness | $= r\sqrt{\frac{1}{2}} = \cdot 7071\,r.$ |
| Rod revolving about its extremity | $= l\sqrt{\frac{1}{3}}.$ |
| " " centre . | $= l\sqrt{\frac{1}{12}}.$ |
| Flywheel rim . . . . | $= \sqrt{\frac{\mathrm{R}^2 + r^2}{2}}.$ |
| Solid sphere . . . . . . | $= r\sqrt{\frac{2}{5}} = \cdot 6325\,r.$ |
| Wire ring, revolving about a diam. | $= r\sqrt{\frac{1}{2}}.$ |
| Thin circular plate " " | $= \cdot 5\,r.$ |
| Thin hollow globe . . . | $= r\sqrt{\frac{2}{3}} = \cdot 8165\,r.$ |
| Solid sphere revolving round an external axis at $c$ distance from centre of sphere . . | $= \sqrt{c^2 + \frac{2}{5}r^2}.$ |
| Cylinder round its axis . . | $= r\sqrt{\frac{1}{2}}.$ |
| " " parallel external axis | $= \sqrt{c^2 + \frac{1}{2}r^2}.$ |

## 34. Vibration and Oscillation.

The vibration of a pendulum is the movement from one extreme of its position to the other. The angle formed by the extreme positions is called the *amplitude* of the vibration. The duration of a vibration is the time occupied in passing through this angle. The beat of a pendulum corresponds to one vibration.

An oscillation is a completed cycle, or two vibrations, permitting a return to the starting point.

Length of a pendulum in London, in inches, to give any required number ($n$) of vibrations per minute

$$= \frac{140{,}901 \cdot 48}{n^2}.$$

## 35. Centre of Oscillation

is that point in a vibrating body, in which, if the whole mass were collected, the body would continue to vibrate through the same angle; and such that any force applied there would generate the same angular velocity in a given time as the same force at the centre of gravity, the parts of the body or system revolving in their respective places. The distance from the point of suspension is equal to the length of a simple pendulum vibrating in the same time.

The time of vibration of a simple pendulum = $\pi \times \sqrt{\frac{\text{length}}{g}}$ $\therefore$ vibration varies as $\sqrt{l}$. Length of London seconds pendulum = 39·1393 inches.

$r$ = radius to centre of gravity.
R = „ „ gyration.
$R_1$ = „ „ oscillation.

$$R_1 = \frac{R^2}{r}.$$

The centre of oscillation is interchangeable with the centre or point of suspension, which then becomes the centre of oscillation.

### 36. PENDULUM.

The formula for a clock pendulum is derived from that for a conical or revolving pendulum, as when the amplitude is small the bob will take the same time to make one revolution as to go straight across the circle and back again. The revolving pendulum forms a cone in space, the sloping side being length of pendulum, say $l$, the height, say $h$, and the radius of base $r$. There will be three forces acting on the bob—the weight acting downwards, the centrifugal force acting horizontally, and the tension of the rod in the direction of the slope of cone. These forces will be in proportion to the three sides of the triangle $h$, $r$ and $l$; hence denoting the centrifugal force by C, we get $h : r :: \mathrm{W} : \mathrm{C}$. Now the centrifugal force will be $\frac{v^2}{r} \times$ mass, or $\frac{\mathrm{W}\, v^2}{g\, r}$, where $v$ is the velocity in feet per second; hence $\frac{h}{r} = \frac{g\, r}{v^2}$, or $h = \frac{g\, r^2}{v^2}$. Now suppose the bob makes one revolution in $t$ seconds, then in one revolution it goes a distance $2\,\pi\, r$; then, as $\frac{\text{distance}}{\text{time}}$ = velocity, we get $v = \frac{2\,\pi\, r}{t}$; substitute this value of $v$ in the equation for $h$, and we get, after cancelling the $r$'s, $h = \frac{g\, t^2}{4\,\pi^2}$, from which $t = 2\,\pi \sqrt{\frac{h}{g}}$. When the amplitude is small, $h$ and $l$ may be taken as equal, so that for a clock pendulum each double beat will be done in $2\,\pi \sqrt{\frac{l}{g}}$ seconds.—*M.I.C.E., Bath.*

### 37. Centre of Percussion

is that point in a body revolving about an axis, at which, if it struck an immovable obstacle, all its motion would be destroyed, or it would not incline either way: it is that point with which, if the body strike against any obstacle, no shock will be felt at the point of suspension: it is the same point in a body as the centre of oscillation.

### 38. Centre of Spontaneous Rotation,

or spontaneous gyration, is that point which remains at rest when a body is struck, or about which it begins to revolve.

### 39. Transmissibility of Force.

Any force acting in a plane may be considered as acting at *any point in its line of direction.* This is called "the principle of the transmissibility of force."

### 40. Parallelogram of Forces.

If three forces act in a plane upon a free point which remains at rest, they may be represented in direction and magnitude by three lines, two of which form adjacent sides of a parallelogram and the third is equal and opposite to the diagonal.

### 41. Equilibrium of Forces.

Forces acting upon a body at rest, but free to move, are said to be in equilibrium.

### 42. Sense of Forces.

The word *sense* is used to assist the word *direction* in dealing with forces; direction may be looked upon as relating to the *position of the line*, and sense as relating to the *position of the arrow-head* with regard to the line.

### 43. Triangle of Forces.

The three lines described under "parallelogram of forces" will also form a triangle, the arrow-heads pointing all the same way round.

### 44. Polygon of Forces.

When more than three forces in one plane acting upon a point are in equilibrium they may be represented in magnitude and direction by lines forming a closed polygon. More fully defined in next paragraph.

### 45. Force Polygon.

When forces acting upon a point are represented by concurrent lines to form a polygon, open or closed, part of which may overlap other parts, it is called the *force polygon*, and when unclosed requires a closing line, representing a new force, known as the *equilibrant*, to balance the remainder. The *resultant* of a number of forces is equal and opposite to their equilibrant. The resultant of any number of forces does not depend upon the order in which they are drawn as the sides of the polygon, provided their *senses* are concurrent.

### 46. Link Polygon.

When forces act together in a system but not through one point, their leverage or turning moment through a point or pole is found by means of the *link polygon* or *funicular polygon* of the forces, which gives the position of the resultant force, otherwise unattainable.

The link polygon is obtained by drawing the force polygon and selecting any point (internal or external) for a pole, drawing lines from the pole to the junctions of the sides of the force polygon, and constructing a new polygon with sides parallel to these lines, commencing at any point on one of the

force lines in its original position, and each side terminating upon meeting the direction of the next force, at which point the next side will commence. The resultant force passes through the last intersections, the direction, sense and magnitude being taken from the force polygon.

### 47. Composition and Resolution of Forces.

*Composition of forces* takes place when a *resultant* is substituted for two or more component forces.

*Resolution of forces* takes place when a single force is replaced by two or more forces equivalent to it, and is the reverse of the former case.

### 48. Moments.

The *moment* of any physical agency is the numerical measure of its importance.—*Thomson and Tait.*

In mechanics, a moment is generally the product of a force into a leverage.

### 49. Moment of a Force.

The product of a force and the perpendicular distance of its direction from any given point, is termed the moment of the force about that point. The moment of a resultant about any point is equal to the sum of the moments of the components about that point.

The term pound-feet would be preferable for moments in leverage to avoid confusion with foot-pounds of energy, both being feet × lbs. but not acting alike. Pound-feet would then belong to statics and foot-pounds to dynamics.

### 50. Principle of the Equality of Moments.

When a body is in equilibrium the sum of the moments of any number of forces that tend to turn the body in one

direction is equal to the sum of the moments of any number of forces that tend to turn the body in the opposite direction.

### 51. Principle of Least Resistance.

Moseley (1833). "If there be a system of forces in equilibrium, among which are a given number of resistances, then is each of these a minimum, subject to the conditions imposed by the equilibrium of the whole." Used in finding line of resistance in arches, &c.

### 52. Couples.

Two equal and opposite forces acting upon a body, parallel but not in the same line, tend to cause rotation, and are called "a couple." The moment of a couple is one of the forces multiplied by the distance between their lines of action, or the two forces × radius to centre on which they would rotate (i.e. half the distance between their lines of action). A couple can only be equilibrated by another couple tending to cause rotation in the opposite direction and having an equal moment.

### 53. Classification of Mechanics.

| *Mechanics of—* | *Known as—* |
|---|---|
| Solids . . . | Statics, Dynamics, Kinematics, Kinetics. |
| Liquids or non-elastic fluids . | Hydrostatics, Hydrodynamics, Hydraulics, Hydrokinetics. |
| Gases or elastic fluids . . | Pneumatics, Aërostatics. |

### 54. Statics and Dynamics.

*Statics* is the science of forces in equilibrium, or pressures.

*Dynamics or kinetics* is the science of forces not in equilibrium, i.e. those producing motion.

### 55. Theory of Machines.

Machines are mechanical arrangements for transmitting force and utilising it in a convenient manner. Power is a constant sum consisting of pressure and movement, or force and velocity, either of which may be increased with a corresponding reduction of the other. The common phrase, "what is gained in power is lost in speed," would be less liable to misapprehension if the word *pressure* were substituted for *power*.

"A machine is an appliance by means of which energy is transferred from one point to another."

### 56. Mechanical Powers.

A *Mechanical Power* is any simple arrangement by which a small force can overcome a greater, and *Mechanical Advantage** is the ratio of the greater force to the less. The Mechanical powers are more properly called *Mechanical Elements, or Simple Machines.* They are commonly described as seven, but all referable to two of the number, thus:—

Lever:—

| | |
|---|---|
| Wheel and axle | Modifications of the lever. |
| Toothed wheels | |
| Pulley . . | |

Inclined plane:—

| | |
|---|---|
| Wedge . . | Modifications of the inclined plane. |
| Screw . . | |

### 57. The Lever, Wheel and Axle, and Toothed Gearing.

Three orders; fulcrum, weight and power, alternately between the other two, principle identical.

* For definition of *Mechanical Efficiency*, see par. 274.

$$P x = W y \;\therefore\; P = \frac{W y}{x}, W = \frac{P x}{y}, x = \frac{W y}{P}, y = \frac{P x}{W},$$

or, taking weight of lever into account,

$$P x = W y + W' y'.$$

In bent levers the length is measured from the fulcrum on a perpendicular to the direction of the force.

*Wheel and Axle.*—Same principle, taking radius as leverage.

*Toothed Gearing.*—Ditto.

## 58. The Pulley.

$n$ = number of cords shortened by raising the weight.

$\frac{W}{n} = P$, or motion of W : motion of P : : P : W.

Pulleys are sometimes divided into three systems as follows:—

*First system.*—Each cord has one end fixed and the other passed round a running sheave. The last cord passes over a fixed sheave.

*Second system.*—Sheaves contained in a pair of blocks, cord passing from strop of upper block round sheave in upper and lower block alternately.

*Third system.*—All cords connected at one end to load, the other end of the first passes over a fixed sheave to strop of a running sheave, second cord passes over this running sheave to strop of next, and so on. Last cord passes over running sheave to the hand. Similar to first system, but inverted.

## 59. Block-and-Tackle, or Pulley Gear.

A *block* is the frame in which the wheels, pulleys, or *sheaves* are secured by means of the pivot, axle or *sheave pin.* The rope or chain passing over the sheaves, or *reeved* through the blocks, is called a *fall.* A combination of blocks, sheaves

and fall is called a *tackle.* A tackle containing more than one rope is called a *Spanish barton.* *Snatch blocks* are blocks containing one sheave and a movable side permitting the bend or *bight* of a rope to be inserted to change its direction or *lead.*

### 60. The Inclined Plane, Wedge and Screw.

*Inclined Plane.*

$$L : H :: W : P \quad \therefore \quad P = \frac{H}{L} W.$$

*Wedge.*—$L : t :: W : P$ (P being direct pressure without friction).

Percussion and friction must be considered in any practical calculation.

*Screw.*—$R$ = radius of lever, $p$ = pitch of screw.

$$2\pi R : p :: W : P.$$

*Differential Screw.*

$$2\pi R : p' - p :: W : P.$$

Hunter's differential screw obtains an extremely slow movement without employing too fine a thread, by means of the difference in pitch between two threads on the same cylinder; it is used for micrometer screws.

*Endless Screw or Worm.*

$N$ = number of teeth in wheel.
$n$ = „ threads in worm.
$R$ = radius of handle or power.
$r$ = „ axle or weight.

$$RN : rn :: W : P.$$

An endless screw is a coarse thread of short length formed upon an axle and geared tangentially into a toothed wheel called a "worm wheel." When the endless screw consists of one thread, each revolution moves the wheel one tooth, and a double thread moves the wheel two teeth for one revolution of the screw.

### 61. Steelyards and Weighing Machines.

*Roman Statera.*—Lever of first order, balance-weight movable.

*Common Steelyard.*—Similar, but with two fulcra on opposite sides of beam, and two corresponding sets of divisions.

*Danish Balance.*— Fixed balance-weight at one end, fulcrum movable.

*Common Balance or Scales.* — Arms equal, substance counterpoised by equivalent loose weights.

*Bent Lever Balance.*—Fulcrum fixed, counterbalance constant, virtual length of arms altered by movement due to weight of substance.

*Spring Balance.*—Weight indicated by amount of tension or compression upon a spring.

*Pooley's Weighing Machine.*—System of compound levers on principle of Roman Statera.

*Armstrong Crane Steelyard.*—Lifting chain passing over pulley on short arm of steelyard, small weights hung to end of long arm, fractional weights coupled together with loose joints so that balance is automatically obtained when sufficient number are lifted.

*Duckham's Weighing Machine.*— Weight indicated by increase of pressure upon liquid enclosed in cylinder hung on lifting chain, weight being hung from piston rod.

*Shapton's Hydrostatic Weighing Machine.*—Similar in principle to Duckham's, but pressure induced by lifting chain passing over sheave on piston rod, instead of load being hung direct.

## 62. Useful Work of Men in Foot-Pounds per Minute.

| Working for | 10 hours per day. | 8 hours per day. | 6 hours per day. |
|---|---|---|---|
| Raising own body . . . . . . | .. | 4250 | .. |
| Working treadmill . . . . . . | .. | 3900 | .. |
| Drawing or pushing horizontally . . . | .. | 3120 | .. |
| " " vertically . . . | .. | 2380 | .. |
| Turning handle . . . . . . . | .. | 2600 | .. |
| Arms and legs, as rowing . . . . | .. | 4000 | .. |
| Wheeling material on ramp . . . . | 720 | .. | .. |
| Throwing earth up 5 feet . . . . . | 470 | .. | .. |
| Raising material with pulley . . . | .. | .. | 1560 |
| " " hands . . . . | .. | .. | 1470 |
| Carrying do. on back, returning empty . | .. | .. | 1126 |

## 63. Comparison of Animal Power.

| | | |
|---|---|---|
| Horse . . . . . | 22,000 | ft.-lbs. per minute. |
| Mule = $\frac{2}{3}$ horse . . | 14,667 | " " |
| Ass = $\frac{1}{5}$ " . . | 4,400 | " " |
| Man = $\frac{1}{10}$ " . . | 2,200 | " " |

## 64. Formulæ for Falling Bodies.

$h$ = Height of fall in feet.

$v$ = Velocity in feet per second.

$g$ = Force of gravity or acceleratrix of gravity in feet = $32 \cdot 2$.

$t$ = Time of fall in seconds.

H = Highest point reached in feet.

T = Time to reach ditto.

V = Velocity imparted otherwise than by gravity.

Falling from Rest.

$$h = \frac{g\,t^2}{2} = \tfrac{1}{2}\,g\,t^2 = \frac{v^2}{2\,g},$$

$$v = g\,t = \frac{2\,h}{t} = \sqrt{2\,g\,h},$$

$$t = \frac{v}{g} = \frac{2\,h}{v} = \sqrt{\frac{2\,h}{g}},$$

Thrown downward.

$$h = \mathrm{V}\,t + \tfrac{1}{2}\,g\,t^2,$$

$$v = \mathrm{V} + \sqrt{2\,g\,h} = \mathrm{V} + g\,t,$$

$$t = \frac{2\,h\,g + \mathrm{V}^2 - \mathrm{V}\,v}{g\,v}.$$

Thrown Upward.

$$h = \mathrm{V}\,t - \tfrac{1}{2}\,g\,t^2 = \frac{\mathrm{V}^2}{2\,g}, \qquad \mathrm{H} = \frac{\mathrm{V}^2}{2\,g},$$

$$v = \mathrm{V} - \sqrt{2\,g\,h} = \mathrm{V} - g\,t, \qquad \mathrm{V} = \sqrt{2\,g\,\mathrm{H}},$$

$$t = \frac{2\,h\,g + \mathrm{V}^2 + \mathrm{V}\,v}{v\,g}, \qquad \mathrm{T} = \frac{\mathrm{V}}{g}.$$

Every uniformly accelerated motion acting freely is subject to similar laws; but it must be understood that these are theoretical formulæ, i.e. only true for bodies falling in vacuo. For precise calculations of bodies falling in the air, the weight of the body must be taken into account, the diminution of the weight due to the upward pressure of the air, and the resistance offered by the air to the passage of the body.

If $\mathrm{W}$ = weight of body,
$w$ = weight of equal bulk of air,
$k$ = retardation due to air resistance (varying approximately as $v^2$),

$$\text{then } g \text{ will become } = \frac{\mathrm{W} - w}{w}\,g - k.$$

### 65. Cartesian Co-ordinates

are measurements in perpendicular directions from points at given distances on two lines at right angles to each other. The distance on each line being taken as the length of the perpendicular on the other, the intersection gives a point which may be one of a series found in the same way, and producing a straight line or curve either regular or irregular.

Cartesian co-ordinates have been used by the author for testing all his experiments and tables of proportions since 1866, but they did not come into general use by engineers for this purpose until about twenty years later, and are even now (1896) not nearly so often applied as their usefulness dictates. The adoption of "squared paper" greatly facilitates the work of plotting the curves.

### 66. Rolling on Inclined Planes.

In rolling a body down an inclined plane, the final velocity, omitting friction, is dependent solely on the height passed through, and will be the same as if falling freely. The average velocities will therefore be the same in descending all planes of equal height, and the times of descending will be proportional to the length.

A body will fall down all chords of a vertical circle to the lowest point in the same time.

### 67. Brachystochrone, or Curve of Quickest Descent.

An inverted semi-cycloid with its base passing through the starting point, and its vertex passing through the terminal point, is the curve of quickest descent; a circular arc with its centre on a vertical line through the terminal point is next; and a straight line joining the extremities is

the slowest although the shortest route. From whatever part of the cycloid the body commences its descent it will always occupy the same time in reaching the bottom.

### 68. Velocity of Sound.

Sound is a function of three independent variables, *acuteness or pitch*, *intensity* and *timbre.*

All sounds travel at the same velocity, being about

1125 feet per second in air at 62° F.
1090 „ „ 32° F.

and 17 times faster in iron, 17 to 11 times in wood, and $4\frac{1}{2}$ times in water.

The velocity of sound is increased by a rise of temperature approximately 1 foot per second for 1° F.

$L$ = length of sound-wave in feet.
$n$ = number of vibrations per second.
$v$ = velocity of sound in feet per second.

$$v = L\,n.$$

Length of vertical vibrating rod fixed at one end = wave length $\div$ 4.

Transverse vibrations of strings.

$n$ = number of vibrations.
$l$ = length of string.
$t$ = tension „
$d$ = density „
$k$ = thickness „

$$n = \frac{1}{k\,l} = \sqrt{\frac{t}{d}}.$$

## 69. Relative Velocities.

| | |
|---|---|
| Falling body | 32 ft. per sec. |
| Race-horse | 50 " |
| Fast train | 90 " |
| Cannon-ball | 1,700 " |
| Gun-cotton (flame) | 15,000 " |
| Earth in orbit | 95,000 " |
| Meteorite | 250,000 " |
| Light | 1,100,000,000 " |

—*Prof. Dewar.*

## 70. The Fastest Mile.

| | |
|---|---|
| Man swimming | 26 min. 52 sec. |
| " walking | 6 " 23 " |
| " in snow shoes | 5 " $39\frac{3}{4}$ " |
| " rowing singly in boat | 5 " 1 " |
| " running | 4 " $12\frac{1}{2}$ " |
| " on tricycle | 2 " $49\frac{2}{5}$ " |
| " on bicycle | 2 " $29\frac{4}{5}$ " |
| " skating | 2 " $12\frac{3}{5}$ " |
| Horse running | 1 " 25 " |
| Railway train | 0 " $40\frac{1}{4}$ " |

—*Practical Engineer*, 1891.

# SECTION II.

# VARIETIES AND PROPERTIES OF MATERIALS.

## 71. Varieties of Iron.

*Wrought Iron.*—Fibrous—Tough—Soft—Ductile at high temperatures, but not fluid—Pressed in moulds at 1500° to 2000° F.—Welded at 2500° to 2800° F.—Easily oxidised—Forged, hammered, or rolled to various shapes—Contains very little carbon.

*Steel.*—Fibrous to crystalline—Containing small amount of carbon may be welded, and with more carbon may be cast—Can be forged—Very tough and strong—May be tempered—Special properties due to some extent to silicon—Used chiefly for tools, and with less carbon for boilers and bridge plates.

*Cast Iron.*—Crystalline—Brittle—Fluid at high temperatures—Takes complicated shapes by casting in a mould—Contains much carbon—The various qualities known as Nos. 1, 2, 3.

## 72. To Distinguish Wrought Iron, Steel and Cast Iron.

If made red hot and hammered, cast iron or malleable cast iron will fly to pieces. If plunged in water while red-hot, steel will harden, while wrought iron will remain soft. They are also distinguished by the grain of the fractured surface. A drop of nitric acid on bright steel will produce a black spot, while wrought iron remains bright; the darker the spot the harder the steel.

## 73. Effect of Carbon in Iron.

| No. | Name. | Percentage of Carbon. | Properties. |
|---|---|---|---|
| 1 | Malleable iron . | 0·25 | Is not sensibly hardened by sudden cooling. |
| 2 | Steely iron . . | 0·35 | Can be slightly hardened by quenching. |
| 3 | Steel . . . | 0·50 | Gives sparks with a flint when hardened. |
| 4 | „ . . . | 1·00 to 1·50 | Limits for steel of maximum hardness and tenacity. |
| 5 | „ . . . | 1·75 | Superior limit of welding steel. |
| 6 | „ . . . | 1·80 | Very hard cast steel, forging with great difficulty. |
| 7 | „ . . . | 1·90 | Not malleable hot. |
| 8 | Cast iron . . | 2·00 | Lower limits of cast iron, cannot be hammered. |
| 9 | „ . . | 6·00 | Highest carburetted compound obtainable. |

—*Bauerman.*

## 74. Common Ores of Iron.

*Oxides :—*

Magnetic Oxide, or Magnetite—from Sweden, Norway, North America, &c.

Red Hæmatite, or Kidney Ore—from Whitehaven and Ulverston.

Specular Iron Ore—is same composition, but composed of crystallised masses; found in Russia, Spain, Elba, &c.

Brown Hæmatite—differs from Red Hæmatite in having water in its composition; from Forest of Dean, Alston Moor, Northamptonshire, &c.

*Carbonates :—*

Spathose Iron Ore, Spathic Ore, or Iron Glance—from Northumberland and Durham.

*Argillaceous :—*

Clay Ironstone or Clay Band—from South Wales, Dudley, North Staffordshire, Yorkshire, &c.

Black Band Ironstone—from Ayrshire and Lanark, containing coaly impurities.

### 75. Scale of Hardness of Minerals.

| | |
|---|---|
| 1. Talc. | 6. Felspar. |
| 2. Rock-salt. | 7. Quartz. |
| 3. Calcite. | 8. Topaz. |
| 4. Fluor spar. | 9. Corundum. |
| 5. Apatite. | 10. Diamond. |

Each mineral in the above list can scratch those preceding and may itself be scratched by those succeeding.

### 76. Roasting and Smelting.

Ore broken into pieces, mixed with coal in large heaps, and allowed to burn slowly to drive off water, carbonic acid gas and sulphur. Called calcining or roasting.

Roasted ore, with earthy matters to form a flux, and fresh fuel to maintain heat, are smelted together in a *blast furnace*, 50 to 100 feet high, to obtain the metal from the ore. Charge consists of say, 5 cwt. ore, 2 cwt. limestone, 5 cwt. coke, repeated every half hour, furnace being kept full. Molten metal run off every 12 hours into channels in sand, long lines called *sows,* branches three or four feet long called *pigs.* Furnace not blown out for six or seven years, unless under special circumstances.

### 77. Chemical Action of Blast Furnace.

The silica, alumina and lime in the ore and flux combine by the aid of heat to form a glassy slag, which floats on the molten metal and runs off near the bottom of the furnace. A small portion of the carbon combines with the iron and

keeps it fluid until drawn off at the tap-hole. The remainder of the carbon of the fuel combines with the oxygen in the ore and the blast to form carbonic oxide ("fire-damp," burning with blue flame) and carbonic acid ("choke-damp," uninflammable) which pass out at the top.

Carbonic oxide (carbon monoxide) will withdraw oxygen from ironstone at temperatures over 500° F.

Carbonic acid (carbon dioxide) will take up more carbon to form carbonic oxide at temperatures exceeding 1000° F.

### 78. Pig Iron.

*Hot-blast and Cold-blast.*—Named from the temperature of the blast used in smelting the ores. Hot-blast generally quicker and more economical, requiring only 30 cwt. of coke per ton of metal instead of 40 cwt., but the metal is not considered to be so strong. Difficult to distinguish the two varieties, but, other circumstances being equal, hot-blast iron has rather a finer grain, duller fracture, with sometimes patches of coarse grains, and usually more impurities. Increasing the blast or reducing the supply of fuel makes the iron whiter, harder and less suitable for re-melting, but better for conversion into wrought iron or steel. Temperature of the blast usually from 600° F. to 1000° F., but higher temperatures have been attained in the Cleveland district.

### 79. Analyses of Pig Irons.

| Description. | C | Mn | Si | S | P |
|---|---|---|---|---|---|
| Foundry—<br>Glengarnock . . | 3·677 | 1·777 | 2·40 | ·602 | 1·010 |
| Bessemer—<br>Workington . . | 4·941 | ·065 | 1·572 | ·038 | ·007 |
| Swedish—<br>Lily . . . . | 4·603 | 1·276 | ·070 | ·006 | ·015 |

SPIEGELS.

| | | | | | |
|---|---|---|---|---|---|
| Ebbw Vale . . . | 3·734 | 8·958 | ·215 | ·064 | ·088 |
| J. Brown & Co.'s . . | 4·675 | 25·12 | ·445 | ·002 | ·056 |
| Ferro-manganese . . | 6·588 | 65·13 | ·187 | ·081 | ·059 |

## 80. CLASSIFICATION OF PIG IRON.

*Bessemer Iron.*—A variety of pig iron made from hæmatite ores for conversion into steel; very free from impurities.

*Foundry Iron.*—All pig iron having grey fracture and large proportion of uncombined carbon; produced under high temperature and full supply of fuel.

*Forge Iron.*—White pig iron, almost free from uncombined carbon, suitable for conversion into wrought iron; produced with low temperature or insufficient fuel, frequently run from blast furnace into iron moulds, rendering it brittle for ease in breaking up.

## 81. REFINING

is a combination of chemical and mechanical processes by which pig iron is deprived of its impurities previously to its conversion into wrought iron.

Refining consists simply of melting the pig iron with coke or charcoal in an open hearth or "refinery furnace," supplied with an air blast so as to impinge on the melted metal and furnish an oxidising atmosphere. This carries off a portion of the carbon, and at the same time removes a portion of the impurities, particularly silicon, in the form of slag. The melted metal, having lost some of its carbon, is then poured into a cast-iron trough lined with loam, kept cold by water circulating below, and the sudden chilling has the effect of converting soft grey iron into hard silvery-white

metal, the carbon which formerly existed in the shape of graphite entering into perfect chemical combination. By this change the fluidity of the iron is reduced, and the subsequent puddling process facilitated.

For common wrought iron the pig metal goes direct to the puddling furnace without undergoing the intermediate refining.

The loss of weight in refining crude iron averages 10 per cent., and the weekly production of a refinery furnace is from 80 to 160 tons.

### 82. Puddling.

*Dry Puddling* is the process of obtaining wrought iron by burning the carbon out of refined cast iron in a reverberatory furnace. The oxygen of the air, at the high temperature employed, combines with the carbon to form carbonic oxide gas, which escapes; and with the silicon to form silica, which runs off as slag. In hand-puddling the mass is stirred about until it is of sufficient tenacity to be lifted out of the furnace in balls or blooms of 60 to 80 lbs. each; a 5 cwt. charge takes about two hours to work off. In Danks' rotary furnace the revolution of the furnace effects the same as the hand labour.

If the operation be stopped before the carbon is all removed, puddled steel is obtained.

*Wet Puddling* or *Pig-boiling* is the more modern process, in which grey unrefined pig iron is converted direct. The bed of reverberatory furnace is lined with broken slag, cinder, scale, &c., fused together, and over these a fettling of soft red hæmatite or "puddlers' mine" is placed. The stages of the puddling process are—(1) graphitic carbon converted into combined carbon, and silicon partly oxidised by roasting and melting; (2) metal drawn from sides, and mixed with that in centre; (3) metal "boiled" for twenty minutes, impurities being oxidised by agitation of the mass; (4) pasty metal "balled" and re-balled, ready for shingling.

### 83. Squeezing, Shingling and Rolling.

After removal from the puddling furnace, at a welding heat, the blooms are put under a heavy trip hammer, a rotary squeezer, or a hydraulic press, to remove the slag and impurities from the spongy mass, and to solidify the metal. They are then passed through chilled rolls, flat or grooved, of various dimensions, to produce the shape required, being drawn down gradually to the finished size.

### 84. Molecular Condition of Iron.

Mr. Jeremiah Head, during a discussion that took place after the reading of a paper "On Reversing Rolling Mills," at the Cleveland Institution of Engineers, said: "I am inclined to think that the term fibrous, when applied to the structure of wrought iron, is really inappropriate and misleading. A truly fibrous material, such as wood, resembles wrought iron only in the appearance of the fracture. But the fibres of wood are not at all ductile, and therefore its appearance, when broken, arises from the broken fibres, of which it is built up, becoming apparent. But the similar appearance of a fractured piece of wrought iron arises from the ductility of the molecules of iron, the apparent fibres having been made for the first time in the act of bending. If we could see into the iron before bending, we should probably find it quite innocent of any fibres, however ductile the quality."

### 85. Crude Wrought Iron.

*Puddled Bar* is the material after passing a bloom through the first series of rolls.

*Merchant Bar* is made by cropping, piling, re-heating, welding and rolling puddled bar.

*Single, double and treble best* signifies the number of times the material is again put through these processes.

## 86. Qualities of Wrought Iron.

(*a*) Iron easily worked hot, and hard and strong when cold, used for rails.*

(*b*) Common iron, used for ships, bridges and sometimes for shafting.

(*c*) Single, double and treble best iron, from Staffordshire and other parts where similar qualities are made. The single or double best is used for boilers. Double and treble best are used for forging.

(*d*) Yorkshire iron, from Lowmoor, Bowling, or other forges where only fine qualities are made. The best Yorkshire iron is very reliable, and uniform in quality. It is used for tyres,* for difficult forgings, for furnace plates exposed to great heat, for boiler plates which require flanging, &c.

(*e*) Charcoal iron, very ductile and of best quality.

—*Unwin's 'Machine Design.'*

## 87. Single and Double Sheet Iron.

Iron sheets, up to No. 20 B.W.G. inclusive, are called *singles;* Nos. 21 to 24, *doubles;* Nos. 25 to 28, *lattens;* and, above No. 28, *extra lattens.* Singles are less than $\frac{3}{16}$ inch in thickness, and when the sheets are less than about $\frac{1}{30}$ inch they are too thin to be rolled separately, therefore two are placed together.

## 88. Iron Rolling Mills.

Weight of piles to produce boiler plates, allowing for waste in the furnace and waste in shearing:—Add for every $\frac{1}{16}$ inch in thickness 1·06 lb. to every square foot of plate over and above the finished weight.

To make boiler plates from slabs, allow one-third more

* Rails and tyres for railway rolling stock are now usually made of a moderately hard mild steel.

than the weight of finished plate; and for re-heating and doubling, 5 lbs. to every 100 lbs. more than one-third must be allowed.

For plates narrower than 20 inches an allowance of 10 lbs. extra to every 100 lbs. must be made for greater waste from shearing.

To make sheets from piles varying from 11 to 30 wire gauge, add one-half more than the finished weight, which is sufficient for waste and shearing upon both bar and sheet.

For merchant bars of all kinds, which are rolled from the pile in one heat, one-fifth more than the finished weight is sufficient to allow for waste and cropping.

As regards wages, the ironworker is paid per ton long weight. What is termed long weight is 2400 lbs. to the ton. —'*Mechanical Progress.*'

### 89. Defects in Wrought Iron.

*Cold-shortness* is produced by the presence of a small quantity of phosphorus as an impurity. The iron is brittle when cold, but of ordinary character when heated. It cracks if bent cold, but may be forged and welded at high temperatures.

*Red-shortness* is generally produced by the presence of sulphur, sometimes by arsenic, copper and other impurities. The iron is tough when cold, but cannot be welded, and is difficult to forge at high temperatures.

### 90. Case-Hardening.

When polished wrought iron is heated to a cherry red and placed in contact with broken prussiate of potash ($K_4FeCy_6$), scraps of leather, &c., the surface is converted into steel by absorption of carbon, and is then hardened by quenching in water. The nitrogen in the mixture is supposed to play an important part.

In locomotive engine factories a mixture of wood charcoal, soda ash and a little lime is used.

Other nitrogenous matters, such as bone-dust, horn, hoof and hide clippings, are often used. If heated with the mixture in a close box the effect is greater. The case-hardening may extend to a depth of about $\frac{1}{16}$ inch for ordinary work, and $\frac{1}{8}$ inch for special cases. The surface shows a mottled appearance before re-polishing.

This method of hardening is used largely for motion blocks, links, pins and eyes, and generally for small articles or portions of them which have to stand much friction. It is cheaper than using steel, but the tendency of the articles to crack and twist is an objection.

### 91. Casting Wrought Iron.

In the "Mitis" process (Nordenfelt's) a small amount of aluminium, say $\frac{1}{2000}$ to $\frac{1}{700}$ by weight, is added to Swedish wrought iron, which causes it to melt and flow at a temperature insufficient to cause the occlusion of gases, and sound tough castings are obtained, having all the properties of the best forged iron, except that they are perfectly homogeneous and free from stratification. Mitis metal will weld and harden. Made by Hansell and Co., Canal Steel Works, Sheffield.

### 92. Definition of Steel.

Steel may be made by the addition of carbon to wrought iron, or the abstraction of carbon from cast iron; both methods are in use commercially; but the old classification, by which the percentage of carbon alone determined the designation, is now nearly discarded, and the better definition would seem to include "all those malleable forms of commercial iron containing iron and carbon produced from a state of fusion into a malleable ingot."

### 93. Varieties of Steel. No. 1.

*Blister Steel* is produced by a process called cementation. Bars of purest wrought iron are placed in a furnace between layers of charcoal powder, and kept at a high temperature (say 1400° F.) for from five to fourteen days. The bars are now brittle, crystalline and more or less covered with blisters. Small regular blisters and fine grain denote good quality. Used for facing hammers, &c., but not for edge tools; used largely for conversion into other kinds of steel.

*Spring steel* is blister steel heated to an orange-red colour, and rolled or hammered.

### 94. Classification of Blister Steel.

| | | | |
|---|---|---|---|
| No. 1. | Spring heat | $\frac{1}{2}$ | per cent. of carbon. |
| „ 2. | Country heat | $\frac{5}{8}$ | „ „ |
| „ 3. | Single-shear heat | $\frac{3}{4}$ | „ „ |
| „ 4. | Double-shear heat | 1 | „ „ |
| „ 5. | Steel-through heat | $1\frac{1}{4}$ | „ „ |
| „ 6. | Melting heat | $1\frac{1}{2}$ | „ „ |

—*Seebohm.*

### 95. Varieties of Steel. No. 2.

*Shear Steel* (sometimes called *tilted steel*) is blister steel cut into short lengths, piled into faggots, sprinked with sand and borax, and placed at welding heat under a tilt hammer. "Single" and "double" shear steel denotes the number of times this process is repeated. Fibrous character now restored. Used for large knives, scythes, plane irons, shears, &c., frequently in conjunction with iron.

*Crucible Cast Steel.*—Originally made by melting fragments of blister steel in covered fireclay crucibles, and running into iron moulds. Now generally made direct from Swedish bars cut up and placed in crucibles, with a small quantity of charcoal, with subsequent addition of spiegeleisen

or oxide of manganese. Variations on this process are known as Heath's and Mushet's, also Tungsten steel, Chrome steel, &c. Forged at low heat, unweldable, fracture grey, crystals very minute.

### 96. Varieties of Steel. No. 3.

*Bessemer Steel.*—Made from grey pig iron containing a large proportion of free carbon, small quantity of silicon and manganese, free from sulphur and phosphorus. Iron melted in cupola, and run into a converter lined with firebrick and suspended on hollow trunnions. Air blown through the metal about twenty minutes, removing all carbon; 5 to 10 per cent. spiegeleisen then added, and blowing resumed long enough to incorporate the two metals. Steel then run out into ladle and moulds. Ingots being porous are reheated and put under steam hammer, then rolled or worked as required. Used for rails, tyres, common cutlery and tools, roofs, bridges, &c.

*Siemens Steel.*—Pig iron melted on furnace hearth; good ore and limestone are then added and heat kept up, process resulting in carbonic acid gas, slag and steel.

### 97. Varieties of Steel. No. 4.

*Siemens-Martin Steel.*—Pig iron melted in furnace, three or four times its weight of heated wrought-iron scrap or steel added, together with spiegeleisen or ferro-manganese, until required proportion of carbon, &c. is obtained, to give steel of requisite hardness; then run into ingot moulds.

*Landore Siemens Steel.*—Iron ore is treated in a rotatory furnace with carbonaceous material, and converted into balls of malleable iron, which are transferred direct to steel-melting furnace. Spiegeleisen, &c. then added. The result is steel of very ductile quality, dense and uniform in texture, and particularly suitable for replacing wrought iron where increased strength is required, in addition to all the best properties of wrought iron.

## 98. Varieties of Steel. No. 5.

*Galy-Calazat Steel.*—Superheated steam is forced through the molten metal, thus oxidising the carbon, and also removing the sulphur and phosphorus as sulphuretted and phosphoretted hydrogen. Used in France.

*Heaton Steel.*—The melted metal is acted on by certain salts, such as nitrate of soda, &c., by which the carbon is oxidised out. Henderson employed fluorides, and Bell, oxide of iron.

*Gilchrist-Thomas,* or *Basic Steel* (1879).—Similar to Bessemer, but difference in the lining of the converter, which is basic or non-siliceous, made from burnt dolomite or magnesian limestone. Phosphorus eliminated quickly and cheaply by combining with the lime; the resulting slag containing phosphorus used as manure when pulverised. The phosphorus being removed by this process, inferior iron may be used.

## 99. Dannemora Cast Steel.

| Carbon. | Temper. | Tools suited for | Remarks. |
|---|---|---|---|
| per cent. $1\frac{1}{2}$ | Razor | Turning and planing, drills, &c. | Great skill required in forging, spoilt if overheated. |
| $1\frac{1}{4}$ | Turning tool | Turning, planing and slotting tools, drills, small cutters and taps. | Not weldable. |
| $1\frac{1}{8}$ | Punch | Mill picks, circular cutters, taps, rimers, small shear-blades, large turning tools and drills, punches and screwing dies. | May be welded with great care. |
| 1 | Chisel | Cold chisels, hot setts, medium-size shear-blades, large punches, large taps, miners' drills for granite. | Will weld with care. |
| $\frac{7}{8}$ | Sett | Cold setts, minting dies, large shear-blades, miners' drills; smiths' tools, as sett hammers, swages, flatteners, fullers, &c. | Will weld without difficulty. |
| $\frac{3}{4}$ | Die | Boiler-cups, snaps, hammers, stamping and pressing dies, welding steel for plane-irons, &c. | Will weld like iron. |

## 100. "Eidsfos Stöbestaal" Cast Steel.

| Quality. | Percentage Carbon. Prof. Eggertz' method. |
|---|---|
| For turning and planing tools for metals | 1·55 to 2·00 |
| ,, slotting and boring tools | 1·45 ,, 1·55 |
| ,, cold chisels, &c. | 1·25 ,, 1·45 |
| ,, edge tools, joiners' tools, &c. | 1·10 ,, 1·25 |
| ,, mining tools, fine springs, twist drills, and for tools requiring toughness | 0·90 ,, 1·10 |
| ,, buffer springs, axles, shafts, tools requiring great toughness, &c. | 0·75 ,, 0·90 |
| ,, gun barrels, and for tools requiring the greatest degree of toughness | 0·40 ,, 0·75 |

## 101. Relative Pig-Iron and Steel Production of Different Countries.

| — | Pig Iron. | Steel. |
|---|---|---|
| | tons. | tons. |
| Great Britain | 7,750,657 | 1,988,045 |
| United States | 4,044,526 | 1,711,920 |
| Germany and Luxemburg | 3,751,775 | 1,200,000 |
| France | 1,628,941 | 527,048 |
| Austria and Hungary | 760,000 | 225,752 |
| Belgium | 714,677 | 146,189 |
| Russia | 498,000 | 300,000 |
| Sweden | 430,504 | 74,241 |
| Spain | 126,269 | 10,000 |
| Italy | 24,778 | 3,450 |
| All other countries | 150,000 | 30,000 |

—*Martineau and Smith.*

### 102. Notes on Cast Iron.

Stronger in compression than wrought iron, but much weaker in tension. Not so safe as wrought iron when subjected to impact or suddenly applied loads.

Used for complex parts of machines, because easier to mould in casting than wrought iron in forging. Principally for wheels, bed-plates and framings.

If thickness of different parts varies much, the castings will be strained in cooling. All edges should be well rounded and hollows filleted.

Expands at moment of solidification in casting, but contracts in cooling. Contraction varies with size and thickness of casting, and quality of metal.

### 103. Qualities of Cast Iron.

*No.* 1. *Grey.*—Soft. Deficient in strength. Used for ordinary castings. Very fluid when melted. 0·6 to 1·5 per cent. carbon chemically combined, 2·9 to 3·7 per cent. mechanically combined.

*No.* 2. *Mottled.*—Variable hardness. Stronger than No. 1. Used for larger castings. More carbon chemically combined, and less mechanically.

*No.* 3. *White.*—Hard. Fusible. Strong. Used for conversion into wrought iron. 3 to 5 per cent. of carbon all chemically combined.

These varieties are mixed in various proportions for special purposes. —*Unwin's 'Machine Design.'*

### 104. Chilled and Malleable Cast Iron.

*Chilled Cast Iron* is ordinary cast iron rapidly cooled during solidification, by using a mould of white or hard cast

iron for the part requiring to be chilled, protected by a wash of loam, causing a chemical combination of the molten iron and carbon. Very hard. Fracture silvery. Direction of crystallisation strongly marked.

*Malleable Cast Iron* is made by heating ordinary castings, preferably of white cast iron, from two to forty hours, according to size, in contact with oxide of iron or powdered red hæmatite, causing partial conversion into wrought iron by abstraction of carbon.

### 105. Toughened Cast Iron.

Toughened cast iron is produced by adding to the cast iron, and melting amongst it, from one-fourth to one-seventh of its weight of wrought-iron scrap, which removes some of the carbon from the cast iron, and causes an approximation to steel. —'*Notes on Building Construction*,' iii. 252.

### 106. Copper.

Very malleable, and hence specially suited for hammering into thin hemispherical pans, rolling into sheets, &c., also ductile to a less degree. Rendered brittle by absorption of carbon, refined and toughened during manufacture, but may be spoilt again by careless manipulation. May be cast. Can be forged cold, or at red heat, but rapidly scales when hot. Addition of 2 to 4 per cent. of phosphorus improves its fluidity and tenacity. Used for fire-boxes, &c., because it is a good conductor of heat, but loses tenacity in proportion to its temperature. Much used in forming alloys.

### 107. Aluminium.

Aluminium, by the Deville-Castner process, is made at a third of its former price, and for many of the lighter parts of

mechanism or delicate machinery may shortly become a substitute for the more common metals, as it does not tarnish even when exposed to damp and impure air.

### 108. Alloys.

*Bronze* is a mixture of (say) 10 copper, 1 tin.

*Brass* is a mixture of (say) 2 copper, 1 zinc.

The terms "higher" and "lower" applied to brass express the greater or less quantity of zinc in the composition. High brass consists of 2 copper to 1 zinc. Low brass 4 copper to 1 zinc.

*Gun-Metal* is a mixture of copper, tin and zinc in various proportions, according to the hardness or toughness required: say 16 copper, 2 tin, 1 zinc. May be also called bronze.

*Muntz-Metal* is a mixture of 3 copper, 2 zinc, and is therefore a brass.

Alloys generally fuse at a lower temperature than the average of the component metals.

### 109. Effect of Alloying with Copper.

*Tin* increases the hardness, and whitens the colour through various shades of red, yellow and grey.

*Zinc* in small quantity increases fusibility without reducing the hardness, in greater quantity increases malleability when cold, but entirely prevents forging when hot; 1 to 2 per cent. of zinc enables sounder castings to be made.

*Lead* increases the ductility of brass, and makes alloy more suitable for turning, filing, &c.; in large quantity causes brittleness.

*Phosphorus* increases the fluidity and tenacity, reduces the effect of the atmosphere, and allows of tempering. It also produces sounder castings.

## 110. Bronze Alloys.

| Name. | Copper | Tin. | Zinc. |
|---|---|---|---|
| Soft gun-metal | 16 | 1 | .. |
| Mathematical instruments | 12 | 1 | .. |
| Pumps (very tough) | 32 | 3 | 1 |
| Pump plungers | 14 | 1 | 1 |
| Small toothed wheels | 10 | 1 | .. |
| Locomotive bearings | 64 | 7 | 1 |
| Engine bearings | 112 | 13 | $\frac{1}{4}$ |
| Locomotive straps and glands | 130 | 16 | 1 |
| Admiralty mixture for valves and mountings | 90 | 10 | $2\frac{1}{2}$ |
| Hard gun-metal for bearings | 8 | 1 | .. |
| Baily's metal | 32 | 5 | 2 |
| G.M. for heavy bearings | 32 | 5 | 1 |
| Maximum hardness for bearings | 5 | 1 | .. |
| Hydraulic valve faces | 4 | 1 | .. |
| Tam-tam (Chinese gongs) | 4 | 1 | .. |
| Bell metal | 4 or 3 | 1 | .. |
| Speculum metal | 2 | 1 | .. |

## 111. Brass Alloys.

| Name. | Copper. | Zinc. | Tin. | Lead. |
|---|---|---|---|---|
| Tough for engine work | 100 | 15 | 15 | .. |
| For turning and fitting | 3 | 1 | .. | $\frac{1}{12}$ |
| Soft for hammering | 7 | 3 | .. | .. |
| Yellow brass | 2 | 1 | .. | .. |
| Stop-cocks and valves | 88 | 10 | 2 | .. |
| Rolling-stock bearings | 77 | .. | 8 | 15 |
| Flanges for brazing | 32 | 1 | .. | 1 |
| Brass for soldering | 8 | 3 | .. | .. |
| Brass, various | 60–92 | 8–40 | $\frac{1}{4}$–3 | $\frac{1}{2}$–3 |
| Muntz-metal sheathing | 3 | 2 | .. | .. |
| Do. locomotive tubes | 66 | 33 | .. | 1 |
| Nails for sheathing | 87 | 4 | 9 | .. |
| Statuary bronze | 90 | 5 | 2 | .. |
| Red brass (Tombak) | 8–10 | 1 | .. | .. |
| Red sheet brass (German) | 11 | 2 | .. | .. |
| Bronze for lamps | 27 | 6 | 1 | 1 |

## 112. Antimony Alloys.

| Name. | Copper. | Tin. | Lead. | Antimony. | Bismuth. |
|---|---|---|---|---|---|
| Babbitt's metal | 1 | 10 | .. | 1 | .. |
| „ lining do. | 1 | 24 | .. | 2 | .. |
| Antifriction do., hard | 1 | 50 | .. | 5 | .. |
| „ „ soft | .. | .. | 81–88 | 12–19 | .. |
| Expanding alloy | .. | .. | .. | 2 | 1 |
| Pewter | .. | 100 | .. | 17 | .. |
| Type metal | .. | .. | 3–7 | 1 | .. |
| Stereotype metal | .. | .. | 77 | 15 | 8 |
| White brass | 1 | .. | 7 | 7 | .. |
| Do. | 3 | 90 | .. | 7 | .. |
| Alloy contracting when heated | .. | 1 | 1 | .. | 2 |

## 113. Nickel Alloys.

| Name. | Copper. | Zinc. | Nickel. | Iron. |
|---|---|---|---|---|
| Common German silver | 60 | 25 | 15 | .. |
| Better „ | 50 | 25 | 25 | .. |
| Chinese Packfong. | 55 | 17 | 23 | 3 |
| Argentan, for hammering or rolling | 40·4 | 25·4 | 31·5 | 2·6 |
| Argentan, for plating | 62 | 19 | 13 | 4–5 |
| „ hard | 57·4 | 25 | 13 | 9 |
| Electro | 8 | 3·5 | 4 | .. |
| Solder for German silver (coarsely powdered) | 8 | 7·5 | 4 | .. |

## 114. Various Alloys.

| Name. | Copper. | Tin. | Zinc. | Various. |
|---|---|---|---|---|
| Silver-bell metal . . | 80 | 10 | 6 | 4 lead. |
| Pot or cock metal . . | 5 | .. | .. | 2 lead. |
| Ship nails . . . | 10 | .. | 8 | 1 iron. |
| Cowper's metal . . | .. | 2 | .. | 1 bismuth. |
| Aluminium bronze . . | 90 | .. | .. | 10 aluminium. |
| Sterro-metal . . . | 60 | 2 | 35 | 3 wrought iron. |
| Gedge's metal . . | 60 | .. | 38·2 | 1·8 „ |
| Delta metal . . . | 55½ | ¼ | 41½ | 1 lead, 1 iron, ¾ manganese. |
| Phosphor bronze . . | 82 | 10 | .. | 7½ lead, ⅛ iron, ⅛ nickel, ¼ phosphorus. |
| Common pewter . . | .. | 83 | .. | 17 lead. |
| British coinage— | | | | |
| Bronze . . . . | 95 | 4 | 1 | |
| Silver . . . . . | 7½ | .. | .. | 92½ silver. |
| Gold . . . . . | .. | .. | .. | 91⅔ gold. |

## 115. Fusible Alloys.

| Melting-point. | Lead. | Tin. | Bismuth. | Zinc. | Corresponding Absolute Steam Pressure.* |
|---|---|---|---|---|---|
| deg. F. | | | | | lbs. |
| 212 | 1 | 3 | 5 | .. | 14·7 |
| 246 | 1 | 4 | 5 | .. | 28 |
| 286 | .. | 1 | 1 | .. | 54 |
| 334 | .. | 2 | 1 | .. | 110 |
| 336 | 2 | 3 | .. | .. | 112 |
| 392 | .. | 8 | 1 | .. | 230 |
| 442 | .. | 1 | .. | .. | .. |
| 472 | .. | .. | 1 | .. | .. |
| 612 | 1 | .. | .. | .. | .. |
| 648 | .. | .. | .. | 1 | .. |

* This column is added to make the table useful for adjusting the composition of fusible safety plugs for boilers.

### 116. Alloys Fusible below 212° F.

| Melting-point. | Lead. | Tin. | Bismuth. | Zinc. | Mercury. | Cadmium. |
|---|---|---|---|---|---|---|
| 212 | 5 | 3 | 8 | .. | .. | .. |
| 210 | 4 | 3 | 8 | .. | .. | .. |
| 203 | 31 | 19 | 50 | .. | .. | .. |
| 200 | 1 | 1 | 4 | .. | .. | .. |
| 149 | 28·5 | 17 | 45·5 | .. | 9 | .. |
| 138 | 8 | 4 | 15 | .. | .. | 3 |

### 117. Solders.

| Name. | Tin. | Lead. | Copper. | Zinc. |
|---|---|---|---|---|
| Plumbers' fine solder . . . | 1 | 1 | .. | .. |
| ,, coarse ,, . . . | 1 | 3 | .. | .. |
| Tinmen's fine solder . . . | 3 | 1 | .. | .. |
| ,, coarse ,, . . . | 2 | 1 | .. | .. |
| Spelter hard ,, . . . | .. | .. | 3 | 2 |
| ,, soft ,, . . . | .. | .. | 1 | 1 |

### 118. Melting-Points of Various Metals, &c.

| | deg. F. |
|---|---|
| Platinum . . . . . | (?) 8500 |
| Wrought iron . . . | 3250 to 4300 |
| Steel . . . . . | 3250 to 4100 |
| Cast iron . . . . | 2200 to 2750 |
| Copper . . . . . . . | 2000 |
| Gun-metal . . . . . . | 1900 |
| Yellow brass . . . . . . | 1850 |
| Aluminium . . . . . . | 1800 |
| Antimony . . . . . . | 810 |
| Zinc . . . . . . . | 750 |
| Lead . . . . . . . | 620 |

MELTING-POINTS—*continued.*

| | deg. F. |
|---|---|
| Bismuth | 480 |
| Tin | 440 |
| Wax | 150 |
| Tallow | 100 |
| Water | 32 |
| Mercury | −38 |

When a substance $\left\{\begin{matrix}\text{expands}\\\text{contracts}\end{matrix}\right\}$ in the act of fusion, the solid parts will $\left\{\begin{matrix}\text{sink}\\\text{rise}\end{matrix}\right\}$ in the liquid. Such substances have their temperature of fusion $\left\{\begin{matrix}\text{raised}\\\text{lowered}\end{matrix}\right\}$ while under pressure. Example $\left\{\begin{matrix}\text{cast iron}\\\text{water}\end{matrix}\right\}$.

### 119. EXPANSION OF METALS BY HEAT.

In fractions of each dimension for one degree Fahrenheit.

| | | | |
|---|---|---|---|
| Wrought iron | ·00001235 | Steel | ·00001145 |
| Cast iron | ·00001127 | Brass | ·00001894 |
| Copper | ·00001717 | Platinum | ·00000884 |
| Lead | ·00002818 | Glass | ·00000861 |

—*Perry.*

Water expands $\frac{1}{22}$ of its bulk from 32° F. to 212° F.
From 32° F. to 572° F. iron expands $\frac{1}{227}$, copper $\frac{1}{177}$.

For a rise of temperature of 10° F.—

| | | | |
|---|---|---|---|
| Iron expands about | | | $\frac{1}{15000}$. |
| Steel | ,, | ,, | $\frac{1}{17000}$. |
| Copper | ,, | ,, | $\frac{1}{10500}$ |
| Brass | ,, | ,, | $\frac{1}{9500}$. |

## 120. Weight of Various Metals in Pounds.

| Name. | Cubic Inch. | Cubic Foot. |
|---|---|---|
| Gold | ·70 | 1203 |
| Lead | ·41 | 710 |
| Copper | ·32 | 550 |
| Gun-metal | ·31 | 530 |
| Brass | ·30 | 525 |
| Muntz metal | ·29 | 510 |
| Steel | ·28 | 490 |
| Wrought iron | ·28 | 480 |
| Tin | ·26 | 460 |
| Cast iron | ·26 | 450 |
| Zinc | ·25 | 435 |
| Aluminium | ·09 | 160 |

## 121. Multipliers to reduce Cubic Feet to Tons.

| | |
|---|---|
| Wrought iron | ·2143 |
| Steel | ·2175 |
| Cast iron | ·2009 |

## 122. Use of Wood in Engineering.

*Pattern-making.*—American yellow pine, New Zealand pine, mahogany, alder, sycamore.

*Bearings.*—Lignum vitæ (end grain).

*Brake Blocks.*—Willow, poplar.

*Pulley Sheaves.*—Lignum vitæ, box.

*Buffer Beams.*—Oak.

*Cylinder Lagging.*—Teak, mahogany, oak.

*Floats for Paddle-wheels.*—Willow, American elm, English elm.

*Sluice Paddles.*—Oak, greenheart.

*Wheel Teeth.*—Hornbeam, beech, holly, apple, oak if in damp place.

*Joiners' Tools.*—Beech, box.

*Hammer Shafts.*—Ash (cleft).

*Tool Handles.*—Ash, beech.

*Shafts and Springs.*—Ash, hickory, lancewood.

*Ordinary framing, piling, &c.*—Yellow deal, Memel, Riga, or Dantzic (creosoted for outdoor work).

*Carriage-building.*—Teak.

*Fender and Rubbing pieces.*—American elm.

*Scaffold Poles.*—Spruce fir.

*Earth Waggons and Barrows.*—Elm.

*Rough Gangways.*—White deals.

### 123. Fir, Deal and Pine.

*Fir* is a general term for wood used in the rough as distinguished from

*Deal*, a general term for wood wrought and used by the joiner.

*Pine* is another general term used for even grained stuff suitable for panels. Also for pitch pine.

Yellow deal and red deal are botanically classed as pine.

White deal and spruce deal are botanically classed as fir.

Deal is not a botanical term.

Planks, deals and battens, and narrow battens are trade terms for boards of certain widths, viz. planks 11 inches, deals 9 inches, battens 7 inches, narrow battens 4½ inches.

### 124. Preserving Ironwork.

*Painting.*—Red lead paints are on the whole most suitable, with a little white lead in the first two coats to permit of the paint being worked well into the corners; good raw linseed oil only should be used to mix them for use. Iron oxide paints are cheaper than lead. Coal tar may be used for rough ironwork, underground pipes, &c.; the tar being heated and ½ lb. to 1 lb. finely sifted slaked lime added per gallon of tar, with sufficient naphtha to thin it for laying on. It must be used hot, but not kept on the fire too long.

*Bower-Barff Process.*—This is specially suited to small pieces exposed to the weather, but not to blows, e.g. rain-water gutters, sanitary fittings and pipes. The articles are raised to a red heat (say 1200° F.) and subjected for some hours (say 6 to 12), to the action of superheated steam, which causes the deposit of a coating of black oxide of iron. It will not stand riveting.

*Dr. Angus Smith's Composition.*—The original recipe was "30 gallons coal tar, 30 lbs. fresh slaked lime, 6 lbs. tallow, 3 lbs. lampblack, 1½ lbs. resin, to be well mixed, boiled twenty minutes and put on hot." The present mixture and method of use vary, but the following may be taken as a good average for dipping cast-iron pipes. For say 2000 miscellaneous pieces (pipes, bends, branches, &c., 3, 4 and 5 inch diameter). Take 7 barrels coal tar, 1 barrel coal oil, and 1 barrel pitch, with 12 tons gas coke for heating them. Provide a wrought-iron tank about 12 feet long so as to take a 9-foot pipe, put in sufficient coal tar to half cover a pipe, upon this sprinkle the proportion of pitch beaten to a powder, and pour the coal oil on the pitch. Clean the pipes thoroughly, make them as hot as the hand can bear, and turn them over in the liquid for two or three minutes, then place them at an angle to drain.

For better work use linseed oil instead of coal oil, increase the temperature of the pipes to 500° to 700° F., or until plumber's solder will melt when pressed against them, and leave them in the liquid for ten minutes after turning them over.

## SECTION III.

# STRENGTH OF MATERIALS AND STRUCTURES.

### 125. Classification of Strains.*

| | |
|---|---|
| *Tension* . . . . | Stretching or pulling |
| *Compression* . . . . | Crushing or pushing. |
| *Transverse Strain* . . . | Cross strain or bending. |
| *Torsion* . . . . | Twisting or wrenching. |
| *Shearing* . . . . | Cutting, or when acting along the grain of timber, detrusion. |

### 126. Definitions of Strain and Stress.

*Strain.*—Every load which acts on a structure produces a change of form, which is termed the strain due to the load. The strain may be temporary or permanent, the former disappearing when the load is removed, the latter remaining as permanent set.

*Stress.*—The molecular forces, or forces acting within the material of a structure, which are called into play by external forces, and which resist its deformation, are termed stresses.

—*Unwin's 'Machine Design.'*

Thus the *strength* of a piece in a given position may be such that a *load* of so many *lbs.* produces a *stress* of so many *lbs. per square inch*, the result being a *strain*, or change of form of a certain amount, whether temporary or permanent,

* See the author's 'Strains in Ironwork.' Spon, 5*s*.

and, when large enough, appearing as stretching, shortening, bending, crumpling, or twisting.

*Intensity of stress* is the pressure per unit of surface, or stress per unit of sectional area.

### 127. Proof Strength.

It was formerly supposed that the proof strength of any material was the utmost strength consistent with perfect elasticity; that is, the utmost stress which does not produce a *permanent set.* Mr. Hodgkinson, however, has proved that a set is produced in many cases by a stress perfectly consistent with safety. The determination of proof strength by experiment is now, therefore, a matter of some obscurity; but it may be considered that the best test known is, *the not producing an increasing set* by repeated application.

—*Rankine's 'Applied Mechanics.'*

### 128. Factor of Safety

is an amount fixed by practical experience, varying with the material used, and the manner of using. It is the ratio of the greatest safe stress to the ultimate resistance of the material, such as $\frac{1}{4}$, $\frac{1}{10}$, &c.; and the calculated resistance of any section, multiplied by the factor of safety suitable to the circumstances, will give the safe working load.

If structures never deteriorated they might be loaded to one-third of their breaking weight with perfect safety, but to guard against ordinary contingencies one-fourth of the breaking weight is the maximum permanent load allowable under any circumstances.

The factor of safety is usually given in its reciprocal form as 4 or 4 to 1, &c., meaning that the ultimate calculated resistance is four times the working load, thus

$$\text{Factor of safety} = \frac{\text{Breaking load}}{\text{Working load}}.$$

## 129. Testing Wrought Iron.*

The strength of a bar should be measured by the *work* done in producing rupture, i.e. the product of the elongation into the mean stress. A convenient approximation to relative toughness is obtained by observing the maximum stress and the elongation in a given length. The length formerly taken was 8 inches, but $6\frac{1}{4}$ inches is now frequently adopted, so that the increase of length in sixteenths of an inch will represent the elongation per cent. The elongation being principally local, the percentage specified for a length of 8 inches $\times \frac{128}{100}$ or $1 \cdot 28$, will give the proper percentage for a length of $6\frac{1}{4}$ inches.

## 130. Testing Cast Iron.

"The best and most certain test of the quality of a piece of cast iron is to try any of its edges with a hammer; if the blow of the hammer make a slight impression, denoting some degree of malleability, the iron is of good quality, provided it be uniform; if fragments fly off and no sensible indentation be made, the iron will be hard and brittle. The utmost care should be employed to render the iron in each casting of an uniform quality, because in iron of different qualities the shrinking is different, which causes an unequal tension among the parts of the metal, impairs its strength, and renders it liable to sudden and unexpected failures. When the texture is not uniform, the surface of the casting is usually uneven where it ought to have been even. This unevenness, or the irregular swells and hollows on the surface of a casting, is caused by the unequal shrinkage of the iron of different qualities." —*Tredgold.*

* See leaflet by the author on 'The 'Behaviour of Materials under Strain.'

## 131. Specification Tests of Cast Iron.

Three bars, each 3 feet 6 inches long, 2 inches deep and 1 inch wide, to be cast on edge in dry mould from each melting at which any of the specified work is cast. These bars to be tested separately as follows:—The lower side, or thin edge, of the casting to be placed downwards* upon rigid bearings, with 3 feet clear span, each bar to deflect not less than $\frac{3}{10}$ inch with a load of 25 cwt. in centre having a bearing not more than 1 inch wide upon the bar, to break with a minimum load of 28 cwt. and an average upon the three bars of not less than 30 cwt.

Samples prepared in lathe to bear $2\frac{1}{2}$ tons per square inch tensile strain before loss of elasticity, and to break with not less than 7 tons per square inch, or an average on three samples of $7\frac{1}{2}$ tons.

Test bars are sometimes cast as projections from an important casting and broken off for testing, but this is a bad method, and gives 10 to 20 per cent. lower results.

## 132. Tests of Cast Iron for Pipe-Making.

"A bar of metal 40 inches long, 2 inches deep and 1 inch wide, the weight of which must not exceed 21 lbs., shall, when supported on edge at points 36 inches apart, sustain a load of 3000 lbs. supported at the middle of its bearing for one hour, and shall under this load deflect at least $\frac{3}{8}$ inch at the middle; and a bar 8 inches long and 1 inch square in section shall sustain a load of 8 tons tensile stress for one hour."

*Note.*—The test bar should deflect $\frac{1}{10}$ inch with 10 cwt., and recover its position when the load is removed. See also par. 602.

* Placed the other way up a reduction of 15 to 20 per cent. in the apparent strength may occur.

## 133. Usual Allowance for Dead Load per Square Inch Sectional Area.*

| — | Breaking Strain. | Safe Load. |
|---|---|---|
| | tons | tons |
| Wrought Iron— | | |
| Tension . . . | 22 | 5 |
| Compression . . . | 18 | 4 |
| Shearing . . . | 20 | 4 |
| Mild Steel— | | |
| Tension . . . | 28 | 7 |
| Compression . . . | 25 | 5 |
| Rivets in shear . . | 24 | 6 |
| Cast Steel— | | |
| Tension . . . | 35 | 8 |
| Compression . . . | 50 | 12 |
| Cast Iron— | | |
| Tension . . . | 7 | 1½ |
| Compression . . . | 42 | 7½ |
| Shearing . . . | 14 | 2½ |

The compression and shearing values assume that the parts are unable to bend.

## 134. Maximum Working Strength in Tons per Square Inch.

| — | Constant Load. | Variable Load. | |
|---|---|---|---|
| Wrought Iron for Machinery. | Tension only 5. Compressn. only 4. | Tension only 3. Compressn. only 2½. | Alternate Tension and Compression 1½. |
| Mild Steel for Machinery. | Tension only 8. Compressn. only 12. | Tension only 5. Compressn. only 7½. | Alternate Tension and Compression 2½. |
| Cast Iron for Machinery. | Tension only 1¼. Compressn. only 6. | Tension only ¾. Compressn. only 4½. | Alternate Tension and Compression ⅜. |

* See paper by the author on 'Strength of Iron and Steel.' Demy 8vo, 16 pp. and folding plates. Spon, 6*d*.

## 135. Ultimate Strength of Various Metals and Alloys.

| Name. | Tension. Tons per sq. inch. | Compression. Tons per sq. inch. |
|---|---|---|
| Mitis iron (cast) | 27 | .. |
| Aluminium bronze | 25 | 50 |
| Phosphor bronze | 25 | 40 |
| Delta metal | 23 | .. |
| Muntz metal | 20 | .. |
| Malleable cast iron | 15 | 45 |
| Copper (wire) | 25 | .. |
| Copper (sheet and bolt) | 15 | 40 |
| Copper (cast) | 10 | .. |
| Gun metal | 12 | 48 |
| Brass | 10 | 25 |
| Zinc | 3 | 15 |
| Tin | 2 | 6 |
| Cast lead | 1½ | 3 |

## 136. Comparative Strength of Iron and Steel Plates.

| Quality. | Ultimate Tensile Strength in tons per sq. inch. | | Elongation per cent. | |
|---|---|---|---|---|
| | With Grain. | Across Grain. | With Grain. | Across Grain. |
| Mild steel | 30 | 28 | 20 | 18 |
| Best Yorkshire | 24 | 22 | 12 | 7½ |
| B. B. Staffordshire | 22 | 19 | 9 | 5 |
| B. " | 20 | 18 | 6 | 2½ |

## 137. Tests of Iron and Steel.

### Physical.

| Brand. | Point of Permanent Set in tons per square inch. | Tension in tons per square inch. | Elongation per cent. |
|---|---|---|---|
| Lowmoor . . . . | .. | 25·50 | 42·15 |
| Staffordshire . . . | 16·82 | 25·57 | 27·50 |
| Mild steel . . . . | 17·92 | 28·86 | 45·00 |
| Medium steel . . . | 20·87 | 33·25 | 35·92 |
| Hard steel . . . . | 25·60 | 39·84 | 30·50 |
| Tool steel . . . . | .. | 57·68 | 14·40 |
| Very hard steel . . . | .. | 68·67 | 7·00 |

### Chemical.

| Brand. | C. | Mn. | Si. | P. | S. |
|---|---|---|---|---|---|
| Parkhead common iron . | ·09 | trace | ·020 | ·316 | ·027 |
| Leeds forge best iron . | ·14 | ·03 | ·110 | ·085 | ·028 |
| Bowling best iron . . | ·11 | trace | ·10 | ·101 | trace |
| Farnley best iron . . | ·11 | ·01 | ·090 | ·096 | ·012 |
| Lowmoor best iron . . | ·10 | ·01 | ·120 | ·142 | ·022 |
| Landore mild steel . . | ·18 | ·64 | ·013 | ·077 | ·074 |
| Mild steel . . . . | ·22 | ·399 | ·062 | ·043 | ·042 |
| Medium steel . . . | ·34 | ·536 | ·024 | ·052 | ·019 |
| Tool steel . . . . | ·97 | ·148 | ·074 | ·034 | ·059 |

## 138. Ankarsrums (Swedish) Cast Iron.

Guaranteed tensile strength = 17·8 tons per square inch.
Average „ „ = 19·5 „ „
Extension on 4 inches . = 0·28 per cent.

—*Westman*, 39 *Lombard Street.*

### 139. Strength of Malleable Cast Iron.

Ultimate tensile strength per sq. inch = 14 tons.
Elongation on 4 inches = $1\frac{1}{2}$ per cent.
Elastic limit = 7 tons.

### 140. Shearing Strength Compared with Tensile Strength.

Is variable, but averages for—

| | | | |
|---|---|---|---|
| Wrought iron | 85 per cent. | Mild steel | 81 per cent. |
| Cast iron | 40 ,, | Hard steel | 64 to 70 ,, |

—*Platt and Hayward.*

### 141. Approximate Strength of Girders.

Safe load in tons distributed when supported at both ends and loaded uniformly.

For cast iron = Sectional area of bottom flange in square inches.

For wrought iron = Gross sectional area of bottom flange plates $\times 2\frac{2}{3}$.

For rolled iron joist = Area one flange $\times$ 4 $\times$ depth inches $\div$ span feet.

For steel joist = Area one flange $\times$ 5 $\times$ depth inches $\div$ span feet.

### 142. Bridges and Girders.*

A = area of one flange in sq. inches at centre.
$a$ = ,, ,, at $x$ feet from one end.
D = depth in feet at centre.
$d$ = ,, ,, at intermediate points.
S = span in feet.
W = load in tons concentrated in centre.
$c$ = constant = stress per sq. inch allowed in flange.

* For general designing, see the author's 'Practical Designing of Structural Ironwork.' Demy 8vo, cloth, 200 pp., with 14 folding plates, containing 180 diagrams. (Spon, 8*s.* 6*d.*)

$$W = \frac{A D c}{\frac{1}{4} S}, \quad A = \frac{\frac{1}{4} W S}{D c}, \quad D = \frac{\frac{1}{4} W S}{A c}.$$

To find section required at any given distance from one end $= a$,

$$a = \frac{A x (S - x)}{(\frac{1}{2} S)^2}.$$

—*W. G. A. & Co., Elswick.*

## 143. Specification Tests of Wrought Iron (Bridge and Girder Work).

| Class. | Tensile Strength, tons per square inch. | Elongation * per cent. at twenty tons. | Contraction per cent. at point of fracture. |
|---|---|---|---|
| Rivet iron . . . | 25 | 10 | 30 |
| Rod and bar iron . . . | 24 | $7\frac{1}{2}$ | 20 |
| Angle and tee iron . . . | 22 | 6 | 15 |
| Plates, with grain . . . | 21 | $4\frac{1}{2}$ | 10 |
| Plates, across grain. . . | 18 | .. | 5 |

* In a length of 8 inches.

## 144. Allowance in Bridges for Changes of Temperature.

Variation of 15° F. alters length of wrought iron as much as strain of 1 ton per square inch.

In exposed situations an allowance of $\frac{7}{16}$ of an inch movement, per 100 feet length, is necessary for the purpose of eliminating the strains due to change of temperature.

—*Graham Smith.*

## 145. Specification Tests—Common Wrought Iron.

| Class. | Tensile Strength, tons per square inch. | Contraction per cent. at point of fracture. |
|---|---|---|
| Rivet iron . . . . . | 22 | 20 |
| Rods, bars and angles . . . | 21 | 12½ |
| Plates . . . . . . | 20 | 10 |

—*Timmins.*

## 146. Specification Tests of Wrought Iron and Steel (Shipbuilding).

| Class. | Tensile Strength, tons per square inch. | Elongation* per cent. on fracture. | Toughness.† |
|---|---|---|---|
| Rivet iron . . . . | 26 | 25 | 650 |
| Rod and bar iron . . . | 24 | 15 | 360 |
| Angle and tee iron . . . | 22 | 12½ | 275 |
| Iron plates, with grain . . | 20 | 7½ | 150 |
| „ „ across grain . . | 19 | 6 | 114 |
| Steel plates (both directions) . | 28 | 20 | 560 |
| „ „ bars and angles . | 30 | 25 | 750 |

* In a length of 6¼ inches.

† Should the actual elongation in sixteenths of an inch, multiplied by the stress in tons per square inch, upon rupture, be more than 10 per cent. under the amounts given in the last column, the material will be rejected.

*Wrought Iron.*—Cold bending in vice—½-inch plate 35°, ⅜-inch plate 55°, $\frac{5}{16}$-inch plate 63°, ¼-inch plate 70°, rivet iron to double close, without cracking.

*Steel.*—Steel plates should be capable of bending to an inside radius of 1½ times their thickness when heated to a low cherry red and cooled in water of a temperature of 58° C. = 82° F. For Admiralty tests, see 'Molesworth,' p. 28.

## 147. Steel and Iron Shipbuilding.

Lloyd's Regulations allow a reduction of 20 per cent. in the scantlings of a steel ship as compared with iron, but the total weight of material used is only about 14 per cent. less. The cost is about the same in steel or iron.

## 148. Definition of Modulus.

The term "Modulus" simply means a constant, coefficient or multiplier, by means of which one series or system of quantities can be reduced to another similar series or system.

## 149. Modulus of Rigidity

is the ratio between the shear stress, in lbs. per square inch, and the shear strain or movement of a particle in inches at one inch from the fixed end.

$$\frac{\text{Stress}}{\text{Strain}} = N.$$

The torsional resistance of any material is proportional to the modulus of rigidity.

## 150. Limit of Elasticity.

The maximum stress per square inch sectional area, which any material can undergo without receiving a visible permanent set, is called its limit of elasticity, or elastic strength.

The average limits of elasticity are—

Wrought iron, 10 tons. Cast iron, 2 tons. Steel, 15 tons.

And the average elongations under a stress of 1 ton per square inch are—

Wrought iron $\frac{1}{10000}$. Cast iron $\frac{1}{7500}$. Steel $\frac{1}{13000}$.
—*Anderson.*

Wrought iron $\frac{1}{12000}$. Cast iron $\frac{1}{6000}$. Steel —
—*Kennedy.*

### 151. Fatigue of Wrought Iron.

When repeatedly strained beyond its elastic limit, wrought iron takes an increasing permanent set, and ultimately breaks with less than its original maximum load; but if periodically annealed before rupture takes place, its elasticity may be renewed. This loss of strength, *being recoverable*, may be termed *fatigue.*

### 152. Hooke's Law of Elasticity.

Hooke' law was "Ut tensio sic vis," which may be freely translated, "As the pull so the stretch"; or in other words, the elongation or compression is proportional to the stress.

### 153. Modulus of Elasticity.

A bar in tension or compression is elongated or shortened by an amount proportionate to the stress within certain limits. Assuming the elongation, on increasing the stress, to continue in the same ratio, a certain point would be reached where the bar would be increased to twice its original length. The weight in lbs. per square inch sectional area of the bar, to produce this result, is the modulus of elasticity (E). The amount depends upon the kind and quality of the material employed, and may vary 50 per cent.

$$E = \frac{\text{stress per unit of section}}{\text{strain per unit of length}}.$$

### 154. Definitions of Modulus of Elasticity.

The modulus of direct elasticity of a material is the ratio of the stress per unit of section of a bar, to the elongation or compression per unit of length, produced by the stress.

—*Unwin's 'Machine Design.'*

It is the weight in lbs. that would stretch or compress a bar, having a sectional area of one square inch, by an amount equal to its own length, called Hooke's law.

—*Cargill's 'Strains.'*

When expressed in feet the modulus of elasticity gives the height to which a body would have to be piled in order that any small addition to its top, of its own substance, might compress the rest to an extent equal to the bulk of that added quantity. —*Dr. Young.*

### 155. Young's Modulus.

Young's modulus of elasticity was originally expressed in feet, and may be obtained from the common table of moduli in lbs. per sq. inch as follows:—

$$\frac{\text{E in lbs. per sq. in.}}{\text{wt. of cub. in. in lbs.} \times 12} = \text{E in feet (Young's Modulus).}$$

### 156. Formula for Elongation by Elasticity.

E = Modulus of direct elasticity (see table).
$l$ = Length in inches.
$w$ = Load per sq. inch sectional area in lbs.
$e$ = Elongation in inches.

$$e = \frac{w \times l}{\text{E}}.$$

Approximately:—

$$\frac{\text{W in tons} \times l \text{ in ft.}}{\text{sq. ins. area} \times 1000} = e \text{ in inches for wrought iron.}$$

## 157. Moduli of Elasticity.

| | lbs. per sq. inch. |
|---|---|
| Cast steel, tempered | 40,000,000 |
| Steel, ordinary | 30,000,000 |
| Wrought-iron bar | 29,000,000 |
| Ditto plate | 25,000,000 |
| Cast iron | 18,000,000 |
| Copper | 16,000,000 |
| Phosphor bronze | 14,000,000 |
| Zinc | 13,000,000 |
| Gun metal | 10,000,000 |
| Brass | 9,000,000 |
| Tin | 5,000,000 |
| Lead | 720,000 |
| Timber, say | 2,000,000 |

The above are sometimes improperly called "Young's Modulus."

## 158. Modulus of Elasticity of Bulk.

The pressure in lbs. per square inch upon the exterior of any substance, or the external stress, produces a diminution of bulk per cubic inch, called the *cubical strain* of the substance. The strain is proportional to the stress, and is equal to the stress divided by a certain number called the *modulus of elasticity of bulk*, and represented by K.

| | | |
|---|---|---|
| K = | Water | 300,000 |
| | Cast iron | 14,000,000 |
| | Wrought iron | 20,000,000 |
| | Steel | 24,000,000 |
| | Copper | 30,000,000 |

### 159. Moment of Inertia.

The moment of inertia of a section is the summation of the areas of all its individual parts, multiplied by the squares of their distances from the neutral axis.

$$\Sigma a y^2 = \mathrm{I}.$$

—*Unwin.*

Moment of inertia is the sum of the moments of resistance in any given section. —*Hurst.*

### 160. Bending Moment, or Moment of Flexure

is the moment of the external forces on one side of a transverse section estimated relatively to the section.

$\mathrm{M} = \frac{\mathrm{E\,I}}{\rho}$ expresses the relation between the bending moment and the curvature of a bar under transverse strain.

—*Unwin.*

### 161. Bending Moment.

The bending moment M at a section is equal to the stress at one inch from the centre of gravity of the section multiplied by the moment of inertia I of the section.

$$\frac{\mathrm{M}}{\mathrm{I}} = \text{stress at 1 inch from neutral axis.}$$

### 162. Neutral Axis.

That layer or plane of fibres in a beam, the length of which is unaltered when the beam is bent by the action of a load, is called the neutral surface, and the line in which this layer cuts any cross section of the beam is called the neutral axis of the section.

### 163. Moment of Inertia.

In such structures as beams, &c., the moment of inertia is determined by the radius of gyration (see par. 33) measured from the neutral axis. It is equal to the area of the section multiplied by the square of the radius of gyration.

If the moment of inertia (I) of any area (A) be given about an axis through the centre of gravity, its value about any parallel axis, such as the neutral axis, at a distance ($d$) will be $= \mathrm{I} + \mathrm{A}\, d^2$.

### 164. Radius of Gyration.

The moment of inertia (I) divided by the area of the section (A) gives the square of the radius of gyration ($r$)

$$r^2 = \frac{\mathrm{I}}{\mathrm{A}}.$$

This is used in ascertaining the strength of struts and columns.

### 165. Modulus of Section, or Strength Modulus

is a function of the dimensions proportional to the moment of resistance of the section. It is the moment of inertia divided by the distance from the neutral axis to the furthest part on the extended or compressed side.

$$\mathrm{Z}_t = \frac{\mathrm{I}}{y_t}. \qquad \mathrm{Z}_c = \frac{\mathrm{I}}{y_c}.$$

Modulus of section × max. strain tension or compression = bending moment [Moment of Resistance].

$$\mathrm{M} = f_t\, z_t = f_c\, z_c.$$

—*Unwin.*

## 166. Moment of Rupture

varies according to the position of load and mode of support, e.g. a beam supported at the ends and loaded in the centre.

$$M_c = \frac{W\,l}{4};$$

and if load be distributed

$$M_c = \frac{W\,l}{8}, \quad \text{or} \quad \frac{w\,l^2}{8}.$$

In a flanged beam $\dfrac{\text{moment of rupture}}{\text{depth}}$ = stress in flange.

In a beam of any section, the stability depends upon the equation—

Moment of Rupture = Moment of Resistance, or $M = K$.

—*Humber.*

*Moment of Load* is the load multiplied by its effective leverage at the point required. The moment of a load divided by the depth of beam will give the horizontal strain on the extreme fibres in its upper and lower sides.

—*Hurst.*

This Moment of Rupture is by other writers called the Bending Moment.

## 167. Modulus of Rupture for Transverse Strains.

The theoretical value of this is the resistance of the material to direct compression or tension, but it is found from experiments on cross breaking that this value is, from various causes, not sufficiently high, and Professor Rankine has adopted a modulus which is 18 times the load required to break a bar of 1 square inch section, supported on two points 1 foot apart, and loaded in the middle between the supports.

C =

| | | | |
|---|---|---|---|
| Cast iron . . | 40,000 | Fir . | 5,000 to 10,000 |
| Wrought iron . | 42,000 | Oak . | 10,000 to 13,600 |

—*Humber.*

The Modulus of Rupture is sometimes called the "Strength Modulus."

## 168. Moment of Resistance.

The moment of resistance of a section is the moment of inertia multiplied by the modulus of rupture and divided by the distance of the neutral axis from the furthest edge of the section.

$$R = \frac{C\,I}{y}.$$

—*Humber.*

The moment of resistance of a beam at any section is the sum of all the products obtained by multiplying the actual longitudinal stress taken at each square inch of the section by its distance from the neutral axis. The moment of resistance in a flanged girder is the longitudinal strength of the weakest flange multiplied by the mean depth of the girder. —*Perry.*

The Moment of Resistance is sometimes called "the Moment of the Section."

The moment of resistance in a beam is proportional to the area of the fibres multiplied by the squares of their distances from the neutral axis. —*Hurst.*

## 169. Working Load for given Moment of Resistance.

$f$ = greatest safe intensity of stress.

$$\text{Let } M = \frac{W\,l}{8} = f\,z, \text{ then } W = \frac{8\,f\,z}{l}.$$

And again,

$$\text{Let } M = \frac{W\,l}{4} = f\,z, \text{ then } W = \frac{4\,f\,z}{l}.$$

### 170. Strength of Structures.

The strength of structures varies as the square of the linear dimensions of similar parts, excluding the effect of weight; but the weight varies as the cube of the linear dimensions. The strength of a structure of any kind is not therefore to be determined by that of its model, which will always be much stronger in proportion to its size. All works, natural and artificial, have limits of magnitude which, while their materials remain the same, they cannot surpass.

—*Lardner.*

### 171. Safe Load on Structures.

| | | |
|---|---|---|
| Cast-iron columns . . . | = $\frac{1}{4}$ | breaking weight. |
| Cast-iron girders for tanks . . | = $\frac{1}{4}$ | breaking weight. |
| Wrought-iron structures . . | = $\frac{1}{4}$ | breaking weight. |
| Cast iron for bridges and floors . | = $\frac{1}{6}$ | " |
| Stone and bricks . . . . . | = $\frac{1}{8}$ | " |
| Timber . . . . . . | = $\frac{1}{10}$ | " |
| Do., temporary structures . | = $\frac{1}{6}$ | " |

—*Molesworth.*

### 172. Safe Load on Floors.

| | | | |
|---|---|---|---|
| Churches and public buildings. | $1\frac{1}{2}$ | cwt. per | sq. foot. |
| Warehouses . . . . | $2\frac{1}{2}$ | " | " |
| Dwelling houses . . . | $1\frac{1}{4}$ | " | " |

### 173. Weight of Men in Crowds.

Mr. Cowper found by experiment that a number of men averaged 140 lbs. per square foot.

Mr. Parsey considers that men packed closely would weigh at least 112 lbs. per square foot, but that in ordinary crowds 80 lbs might be taken as sufficient.

On the Continent it is not usual to estimate so high.

Belgians weigh about 140 lbs. each, Frenchmen 136 lbs., while Englishmen weigh 150 lbs.

Mr. F. Young states 80 lbs. per square foot is quite safe in practice.

Mr. Thomas Page packed picked men on a weighbridge with a result of 84 lbs. per foot super.

Mr. George Gordon Page says that for troops on march $35\frac{1}{4}$ lbs. per square foot is sufficient.

The usual practice is to assume the live load as 100 lbs. per square foot. —*A. T. Walmisley.*

| | lbs. per sq. foot. |
|---|---|
| French practice (quoted by Stoney and Trautwine) . . . . . . . | 41 |
| Hatfield in 'Transverse Strains,' for soldiers . . . . . . . | 70 |
| Nash, architect of Buckingham Palace (quoted by Tredgold) . . . . . | 120 |
| W. K. Kernot, Working Men's College, Melbourne . . . . . . . | 126 |
| Prof. W. C. Kernot, Melbourne University. | 143·1 |
| B. B. Stoney, in 'Stresses' . . . . | 147·4 |

*Prof. Kernot.*

## 174. Flat Cast-Iron Floor Plates.

$$\text{Thickness ins.} = \frac{\sqrt{\text{load lbs. sq. ft.}} \times \text{length ins.}}{380}.$$

## 175. Theorem of Three Moments.

If A B C be three consecutive supports of a continuous girder of any number of spans, whether equal or unequal, and $l_1$ $l_2$ the consecutive spans; then let $p_1$ $p_2$ = the loads per unit of span on $l_1$ $l_2$ respectively; and $M_1$ $M_2$ $M_3$ = the bending moments on A B and C respectively. The relation between $M_1$ $M_2$ and $M_3$ is always expressed by the equation

$$M_1 l_1 + 2 M_2 (l_1 + l_2) + M_3 l_2 = \frac{1}{4} (p_1 l_1^3 + p_2 l_2^3).$$

### 176. Load on the Supports of Continuous Girders

of equal spans uniformly loaded, the load on each span being unity, and the supports perfectly level and rigid.

| No. of Spans. | Abut-ment. | 1st Pier. | 2nd Pier. | 3rd Pier. | 4th Pier. | 5th Pier. | 6th Pier. | 7th Pier. |
|---|---|---|---|---|---|---|---|---|
| 2 | ·375 | 1·25 | .. | .. | .. | .. | .. | .. |
| 3 | ·4 | 1·1 | .. | .. | .. | .. | .. | .. |
| 4 | ·393 | 1·143 | ·93 | .. | .. | .. | .. | .. |
| 5 | ·394 | 1·131 | ·989 | .. | .. | .. | .. | .. |
| Infinite | ·3943 | 1·134 | ·9641 | 1·0096 | ·9974 | 1·0007 | ·9998 | 1·00 |

When the number of spans exceeds five, the loads on the supports are nearly the same as when the number is infinite.

### 177. Approximate Safe Load on Columns and Piers.

Cast-iron column or stanchion with metal $\frac{3}{4}$ inch thick or upwards.

| | | | |
|---|---|---|---|
| Up to 10 | diameters long | 5 | tons per sq. inch. |
| 10 to 15 | ,, | 4 | ,, |
| 15 to 20 | ,, | 3 | ,, |
| 20 to 25 | ,, | 2 | ,, |
| 25 to 30 | ,, | $1\frac{1}{2}$ | ,, |
| 30 to 35 | ,, | $\frac{3}{4}$ | ,, |

If less than $\frac{3}{4}$ inch thick take $\frac{1}{4}$ ton per sq. inch less for each $\frac{1}{8}$ inch less in thickness.

| | | | |
|---|---|---|---|
| Hard York or Portland stone piers | 12 | tons | per foot super. |
| Stock brick in cement, if covered with stone template . . | 6 | ,, | ,, |
| Do. without do. . | 4 | ,, | ,, |

### 178. Effect of Load not being Axial.

When the centre of pressure, or resultant of the forces acting on a cross section, does not coincide with the centre of gravity of the section the strength is reduced and the maximum stress increased as follows :—

$W$ = total load tons.
$d$ = distance of centre of pressure from neutral axis of section (i.e. line through centre of gravity).
$A$ = area of section in sq. feet.
$s$ = mean stress in tons per sq. foot.
$S$ = maximum " "
$D$ = distance of point of maximum stress from neutral axis.
$I$ = moment of inertia of the section.

$$s = \frac{W}{A}, \qquad S = s\left(l + d\frac{DA}{I}\right).$$

### 179. Wrought-Iron Struts.

Angle, tee, or cross section, ends fixed.

$l$ = length, inches.
$d$ = least width, inches.
$f$ = factor of safety = 5 to 8.

Safe load lbs. per sq. inch, sect. area $= \dfrac{42000}{f} - 120\dfrac{l}{d}$.

" tons " " $= \dfrac{20}{f} - \cdot 05\dfrac{l}{d}$.

### 180. Notes on Iron Columns.

When the length is 26·4 times the diameter, pillars, columns, or vertical struts are of equal strength whether of wrought or cast iron; when shorter, cast iron is stronger; when longer, wrought iron is stronger. —*Gordon.*

Cast-iron columns under 5 diameters long, fail entirely by crushing; from 5 to 20 diameters, partly by crushing partly by bending; over 20 diameters entirely by bending.

## 181. Strength of Cast-Iron Columns.

*Cast-iron hollow columns :—*

$d$ = external diameter inches ($\frac{1}{10}$ to $\frac{1}{30}$ length).
$t$ = thickness in inches (not to exceed $\frac{1}{6}\,d$).
L = length in feet (ends flat and fixed).

$$\text{Safe load tons per sq. inch} = (t + 1)\,\frac{2\,d}{\text{L}}.$$

*Cast-iron solid columns :—*

W = breaking weight tons per sq. inch.
$r$ = ratio of length to least diameter.

$$\text{W} = \frac{42}{1 + \cdot 003\,r^2}.$$

—*Planat.*

$d$ = diameter inches, $l$ = length feet.

$$\text{Safe load tons} = \frac{4\,d^4}{4\,d^2 + \cdot 18\,l^2}.$$

Safe load hollow column = difference of solid columns of internal and external diameters.

—*Bourne.*

## 182. Approximate Safe Loads on Posts.

Fir post, 10 diameters long, $\frac{2}{10}$ ton per sq. inch.
Oak „ „ $\frac{3}{10}$ „

Approximate safe permanent load in tons on square timber posts of fir

$$= 50\,\frac{d^4}{l^2}.$$

—*Reuleaux.*

Another rule for fir posts, flat ends:

$$\text{Working load lbs. per sq. inch} = 1000 - 10\,\frac{l}{d}.$$

—*Stanwood.*

Another rule: Approx. safe load on fir post:

$$\frac{b\,\text{ins.} \times d\,\text{ins.}\left(60 - \dfrac{l\,\text{ins.}}{b\,\text{ins.}}\right)}{250} = \text{safe load, tons.}$$

For oak posts:

$b$ = breadth of side in inches.
L = length in feet.

$$\text{Safe load in lbs.} = \frac{b^3 \times 3960\,\text{L}}{4\,b^2 + \frac{1}{2}\,\text{L}^2}.$$

—*Bourne.*

## 183. Pillars and Struts of Wood.

$d$ = diameter or width narrowest side, inches.
F = crushing force, short specimen, tons per sq. inch.
$l$ = length in inches.
S = sectional area, sq. inches.
W = breaking weight in tons.

$$\text{W} = \frac{\text{F S}}{1 + \dfrac{l^2}{200\,d^2}}. \qquad \text{F} = \begin{cases} \text{Oak } 3\cdot2 \\ \text{Fir } 2\cdot5 \end{cases}$$

—*Rankine.*

W = safe load tons total.
$a$ = sectional area, sq. inches.
$d$ = least diameter or width side, inches.
L = length, feet.

$$\text{W} = 1\cdot0752\,a\,\frac{d^2}{\text{L}^2} \text{ or W} = \begin{cases} \cdot45\,a \text{ for oak.} \\ \cdot27\,a \text{ for fir.} \end{cases}$$

The lesser of these two values to be taken. If unseasoned, the safe load will only be one-half above.

### 184. Ultimate Strength of Wood Posts.

24 diameters long = $\frac{1}{2}$ crushing load on short specimens.
48 " " = $\frac{1}{6}$ " " "
72 " " = $\frac{1}{18}$ " " "

### 185. Ultimate Strength of Timber.

| Name. | Tension. Per sq. inch. | Compression. Per sq. inch. |
|---|---|---|
| Ash . . . . . | $7\frac{1}{2}$ tons | 4 tons |
| Beech . . . . | 5 " | 4 " |
| Elm . . . . . | 6 " | 4 " |
| Memel and Riga fir . . | 5 " | $2\frac{1}{2}$ " |
| Larch . . . . | 5 " | $1\frac{1}{2}$ " |
| Honduras mahogany . | $4\frac{1}{2}$ " | $3\frac{1}{2}$ " |
| English oak . . . | 6 " | 4 " |
| Dantzic " . . . | $5\frac{1}{2}$ " | $3\frac{1}{2}$ " |
| Quebec " . . . | $5\frac{1}{2}$ " | 3 " |
| Teak . . . . | 7 " | 5 " |
| Pitch pine . . . | $4\frac{1}{2}$ " | 3 " |
| Hornbeam . . . | 4 " | $3\frac{1}{2}$ " |

### 186. Maximum Safe Load on Timber in Direct Compression.

Fir and deal:

With the grain = 450 lbs. per sq. inch.
Across " = 250 " "

### 187. Formula for Strength of Timber Beams.

$s$ = span feet. $b$ = breadth inches. $d$ = depth inches.
B.w. = breaking weight cwts. centre. $c$ = constant.

$$\text{B.w.} = \frac{b\,d^2}{s}\,c.$$

When load is not central, dividing span into $x$ and $y$

$$B.w. = \frac{s\,b\,d^2}{4\,x\,y}\,c.$$

Safe deflection = $\frac{1}{40}$ inch per foot span.

In calculating scantling of timber for practical use under tension or transverse stress, $1\frac{1}{2}$ inches must be added to each dimension to allow for the contingency of a knot occurring in the piece.

When loaded on top and supported at the ends, the soundest side of a square beam should always be placed downwards, and if rectangular then the soundest of the narrow sides should be downwards.

### 188. Constants for Strength of Rectangular Beams

= weight in cwts. in centre required to fracture a bar 1 inch square and 1 foot long.

| | | | |
|---|---|---|---|
| Wrought iron | 22 | Quebec and Baltic oak | 4·5 |
| Cast iron | 18 | Memel Dantzic and Riga fir | 4 |
| Brass | 10 | Spruce fir and larch | 3·5 |
| Greenheart | 8 | English elm | 3 |
| Teak | 6 | | |
| English oak | 5 | | |

### 189. Experiments on Rectangular Beams of Selected Pine.

B.w. lbs. centre = $6080\,\frac{b\,d^2}{l}$ (all inches); or if $l$ in feet

then = $506\frac{2}{3}\,\frac{b\,d^2}{L}$.

If a given rectangular beam be under a given strain by a given load in a given position which divides the span in

the proportions $x$ and $y$, then to obtain the same strain when the load divides the span in the proportions $m$ and $n$, the depth $d$ will be altered to $d_1 = d \times \sqrt{\frac{m\,n}{x\,y}}$.

### 190. Proportions of Beams for Strength and Stiffness, with Minimum Amount of Material.

| Strongest | Stiffest |
|---|---|
| $d : b :: \sqrt{2} : 1$ | $d : b :: \sqrt{3} : 1$ |

Aproximately for strength, $d$ to $b$ as 1 to ·7; and for stiffness as 1 to ·58; but 1 to ·5 is often used for beams, where the ends can be fixed sideways, because two can be cut out of a square log, and 1 to ·33 or three out of a square log when intermediate staying can be applied, as in joists.

Out of a round log of diameter $d$ the strongest beam that can be cut is ·816 $d$ × ·577 $d$, and the stiffest ·866 $d$ × ·5 $d$

### 191. Approximate Proportions of Beams.

| Strength. | Stiffness. | Convenience. |
|---|---|---|
| inches | inches | inches |
| 12 × 8½ | 12 × 7 | 12 × 9 or 12 × 6 |
| 10 × 7 | 10 × 6 | 10 × 5 |
| 9 × 6½ | 9 × 5¼ | 9 × 6 or 9 × 4½ |
| 8 × 5½ | 8 × 4¾ | 8 × 6 or 8 × 4 |
| 7 × 5 | 7 × 4 | 7 × 4½ or 7 × 2 |
| 6 × 4½ | 6 × 3½ | 6 × 4 |
| 5 × 3½ | 5 × 3 | 5 × 3 |
| 4 × 3 | 4 × 2½ | 4 × 3 or 4 × 2½ |
| 3 × 2 | 3 × 1¾ | 3 × 2 |

## 192. Strength and Stiffness of Timber.

| Name. | Stiffness. | Strength. | Resilience. |
|---|---|---|---|
| Ash | 89 | 119 | 160 |
| Beech | 77 | 103 | 138 |
| Riga fir | 98 | 80 | 64 |
| Memel fir | 114 | 80 | 56 |
| Larch | 79 | 103 | 134 |
| Honduras mahogany | 93 | 96 | 99 |
| English oak | 100 | 100 | 100 |
| Dantzic ,, | 117 | 107 | 99 |
| Quebec ,, | 114 | 86 | 64 |
| Teak | 126 | 109 | 94 |
| Pitch pine | 73 | 82 | 92 |

Oak being taken for comparison as = 100.

## 193. Resilience.

*Resilience* or *Spring* is the quantity of mechanical work required to produce the proof stress on a given piece of material, and is equal to the product of the proof strain or alteration of figure, into the mean load which acts during the production of that strain: that is to say, in general, very nearly one-half of the proof load.

The *Resilience* or *Spring* of a *Beam* is the work performed in bending it to the proof deflection:—in other words, the energy of the greatest shock which the beam can bear without injury: such energy being expressed by the product of a weight into the height from which it must fall to produce the shock in question. This, if the load be concentrated at or near one point, is the product of half the proof load into the proof deflection. —*Rankine.*

The resistance of beams to transverse impact, or a suddenly applied load, is termed their resilience. It is simply proportional to the mass or weight of the beam, irrespective of the length or the proportion between the depth and breadth.

Thus, if a given beam break with a certain steady load, a similar beam of twice the length will break with half the load applied in the same way; but if the short beam be deflected or broken by a certain falling load, the long beam will require double the load dropped from the same height or the load dropped from twice the height, to produce the same effect. —*Anderson's 'Strength of Materials.'*

The work done in deforming a bar up to the elastic limit is termed the resilience of the bar. —*Unwin.*

## 194. Timber Trees.

| Name. | Mean Diameter of Trunk. | Average Length of Trunk. |
|---|---|---|
| | inches | feet |
| Ash | 23 | 38 |
| Beech | 27 | 44 |
| Chestnut | 37 | 44 |
| Elm | 32 | 44 |
| Riga fir | 20 | 75 |
| Larch | 33 | 45 |
| Mahogany | 72 | 40 |
| Norway spruce | 15 | 60 |
| Canadian oak | 34 | 53 |
| English oak | 32 | 42 |
| Sycamore | 29 | 32 |

—*Law.*

## 195. Sizes of Fir Timber in Balk.

| | | |
|---|---|---|
| Stettin | 18 to 20 in. square. | |
| Dantzic | 14 ,, 16 ,, | 40 to 50 ft. long. |
| Memel | 13 ,, | 35 ,, |
| Riga | 12 ,, | 40 ,, |
| Swedish and Norwegian | 8 ,, 12 ,, | |

### 196. Notes on Pile-driving.*

Gauge, guide, or main piles are whole timbers 9 to 15 inches square, driven about 10 feet apart.

Waling-pieces, or walings, are horizontal timbers formed of half balks secured to the guide piles in pairs, one pair near the top and another pair near low-water mark. These serve as guides in driving the intermediate piles.

Sheet piling is formed of piles 9 inches by $4\frac{1}{2}$ inches or 12 inches by 6 inches, the bottom end chisel-shaped and raking so as to be drawn towards the piles already driven.

Intermediate piles may be whole timbers or sheet piling according to circumstances.

Puddle is well punned clay filled in between the walls of a cofferdam to prevent passage of water.

All piles should be shod; if unprotected the wooden points would break and cause the piles to drive out of line. Shoes for main piles weigh from 10 to 15 lbs. each, and for sheeting piles from 5 to 8 lbs. each.

The heads of all piles should be hooped, ringed or rung to prevent them from splitting under the blows of the ram or monkey.

When piles have to be scarfed to obtain sufficient length, the scarfs should break joint at 6 feet intervals in adjacent piles.*

### 197. Formulæ for Pile-driving.

$\mathrm{P}$ = ultimate supporting power in tons = $\mathrm{W} f$.

$\mathrm{W}$ = safe working load in tons.

$w$ = weight of ram in lbs. = not less than $\dfrac{\mathrm{L}\, s}{4}$.

$\mathrm{H}$ = height of fall in feet.

$d$ = set, or distance driven by last blow, in inches.

$\mathrm{L}$ = length of pile in feet.

* See paper on 'Timber Piling in Foundations and other Works,' 2nd ed., 24 pp. and folded plate (Spon, 1*s*.).

$s$ = mean sectional area of pile in square inches.
$f$ = factor of safety = say from 2 to 3.
$x$ = energy of last blow in foot-tons $= \dfrac{w\,H}{2240}$.
$c$ = constant $= \dfrac{125\,s}{L}$.

$$P = \sqrt{c\,x + \left(\frac{c\,d}{24}\right)^2} - \frac{c\,d}{24}.$$

$$x = \frac{P\,d}{12} + \frac{P^2}{c}.$$

$$d = 12\left(\frac{x}{P} - \frac{P}{c}\right).$$

$$H = \frac{2240\,x}{w}.$$

## 198. Timber Roofs.

$\frac{1}{5}$ span in feet = thickness of truss in inches.
0·3 span in feet + 3 = depth of tie-beam in inches.

King or queen post square in middle, width ends = twice thickness.

King post truss up to 30 feet span, queen post truss for larger spans.

## 199. Wind Pressures.*

36 lbs. per sq. foot steady wind pressure, and 56 lbs. per sq. foot for gusts in exposed situations, is sufficient to provide for in roofs, bridges, &c., for ordinary cases.

* See papers by the author on 'Wind Pressure on Roofs,' 2nd ed., demy 8vo, 12 pp., with folded plate (6*d.*), and 'The Force of the Wind,' 8 pp. (3*d.*)

## 200. Approximate Weight of Timber Roofs.

| | | | | |
|---|---|---|---|---|
| King or queen truss, span in feet$^2$ | = lbs. per truss. | | | |
| Common rafter and purlins . | = | 7 lbs. | per ft. | sup. |
| $\frac{3}{4}$-inch slate boarding . . | = | $2\frac{1}{2}$ | ,, | ,, |
| Slate battens . . . . . | = | $1\frac{1}{4}$ | ,, | ,, |
| Roofing felt . . . . . | = | $\frac{1}{2}$ | ,, | ,, |
| Slates and nails (general) . | = | 9 | ,, | ,, |
| Ceiling (complete). . . . | = | 12 | ,, | ,, |
| Snow . . . . . . | = | $7\frac{1}{2}$ | ,, | ,, |
| Wind (horizontally) . . | = | 56 | ,, | ,, |

The combined effect in vertical load with trusses usual distance apart may be taken at 60 lbs. per foot super.

## 201. Galvanised Corrugated Iron Roofing.

| Thickness B.W.G. | Size of Sheets. | Weight per Square. cwt. | qrs. | lbs. |
|---|---|---|---|---|
| 16 | 6 feet × 2 feet to 8 feet × 3 feet | 3 | 0 | 14 |
| 18 | ,, ,, | 2 | 1 | 6 |
| 20 | ,, ,, | 1 | 3 | 6 |

To be laid with 6-inch laps and double riveted at joints; 3 lbs. of rivets required per square.

## 202. Weight of Materials for Estimating.

| | | | |
|---|---|---|---|
| Wrought iron . . . . . | 480 | lbs. per | cub. ft. |
| Cast iron . . . . . . | 450 | ,, | ,, |
| Gun-metal and brass . . | 530 | ,, | ,, |
| Cast steel . . . . . . | 504 | ,, | ,, |
| Mild steel . . . . . | 490 | ,, | ,, |
| Lead . . . . . . | 700 | ,, | ,, |
| Copper . . . . . . | 550 | ,, | ,, |
| Zinc . . . . . . . | 450 | ,, | ,, |
| Greenheart . . . . . | 60 | ,, | ,, |
| Oak . . . . . . . | 50 | ,, | ,, |
| Fir . . . . . . . | 40 | ,, | ,, |
| Granite . . . . . . | 160 | ,, | ,, |
| Bramley Fall and Hard York . | 140 | ,, | ,, |

## 203. Sheet Copper.

Sheets 4 feet by 2 feet.

| | | | | |
|---|---|---|---|---|
| B.W.G. 22 | = | 1·25 lbs. | per ft. | sup. |
| 24 | = | 1·0 | „ | „ |
| 26 | = | ·75 | „ | „ |
| 28 | = | ·5 | „ | „ |

## 204. Sheet Lead.

Cast sheets, 6 feet wide × 16 to 18 feet long.
Milled sheets, 7 feet wide × about 25 feet long.
Made 3 to 10 lbs. per foot super.

Lbs. per foot × ·017 = thickness in decimals of an inch.
1 sq. foot, 1 inch thick, weighs 60 lbs.

## 205. Sheet Zinc.

Sheets 2 ft. 8 in. and 3 ft. wide, 7 ft. and 8 ft. long.

| Gauge. | | Oz. per ft. sup. | Corresponding to old B.W.G. | Thickness inches. |
|---|---|---|---|---|
| (Z.G.) No. 10 | = | $11\frac{1}{2}$ | 25 | ·019 |
| 12 | = | $15\frac{1}{8}$ | 23 | ·025 |
| 14 | = | $18\frac{3}{4}$ | 21 | ·031 |
| 16 | = | $24\frac{3}{4}$ | 19 | ·041 |

1 sq. foot, 1 inch thick, weighs $37\frac{1}{2}$ lbs.

## 206. Handy Numbers for Weight of Iron.

*Wrought iron*:—

Sectional area, square inches × $3\frac{1}{3}$ = lbs. per foot run.
Cubic inches × ·28 = lbs.
Round iron, $d^2 \times 2\cdot62$ = lbs. per foot run.
Square feet per $\frac{1}{8}$ inch thick × 5 = lbs.
For weight of rivets in plate girders, take 5 per cent. of weight of plates and angle irons, and in lattice or box girders $2\frac{1}{2}$ per cent.

*Cast iron* :—

Sectional area, square inches × 3·2 × length in feet = lbs.

Weight of wrought − 5 per cent. = weight of cast.

23 cubic inches = 6 lbs.

40 lbs. per square foot, 1 inch thick, is sometimes taken to allow for inaccurate casting.

*Mild Steel* :—

Weight of wrought iron + $2\frac{1}{2}$ per cent. = weight of mild steel.

Some designers add $\frac{1}{48}$ and some $\frac{1}{50}$ to weight in wrought iron.

## 207. Market Sizes of Plates.

In a well-assorted specification for a fair quantity of material, Staffordshire plates may now be obtained at a minimum price up to 10 cwt. each, 30 feet long and 5 feet 6 inches wide, and Cleveland plates up to 15 cwt. each, 30 feet long and 5 feet wide. —*Walmisley*, 1888.

For ordinary prices mild steel plates may be obtained in one piece up to 20 cwt., 30 feet long, 6 feet 6 inches wide, $1\frac{1}{2}$ inches thick, or 60 feet super., and to double these limits for a moderate addition to the price.

## 208. Limits of Ordinary Prices, Staffordshire District.

*Plates.*—Weight 8 cwt., length 20 feet, width 4 feet 6 inches, 40 feet super., shape regular.

*Angle and Tee Irons.*—Length 40 feet, size $2\frac{1}{2}$ inches by $2\frac{1}{2}$ by $\frac{1}{4}$ up to 8 united inches.

*Bars.*—(Round and square), diameter $\frac{1}{2}$ inch to 3 inches, length 25 feet.

*Bars.*—(Flat), size 1 inch by $\frac{1}{4}$ inch up to 6 inches by 1 inch, length 25 feet.

## 209. Extract from the Cleveland List of Limits and Extras.

*Weight*, to 10 cwt. Beyond, 10*s.* per ton for every cwt. or portion thereof.

*Length*, to 20 feet. Beyond, 2*s.* 6*d.* per ton per foot or part thereof.

*Width*, 12 inches to 54 inches. For $\frac{3}{16}$ inch and $\frac{1}{8}$ inch thick, 12 inches to 48 inches. Beyond or under, 5*s.* per ton per inch or part thereof.

| | | | |
|---|---|---|---|
| *Area* | 60 | sq. feet for thicknesses from $\frac{1}{4}$ inch to 1 inch inclusive. | |
| | 48 | „ | $\frac{3}{16}$ inch thick. |
| | 36 | „ | $\frac{1}{8}$ „ |

Beyond (if sellers undertake them at all), 1*s.* per ton per sq. foot.

Boiler plates, except B B B boiler, 48 sq. feet.

„ „ B B B boiler, 36 sq. feet.

Beyond (if undertaken), 2*s.* 6*d.* per ton per sq. foot.

*Thickness*, $\frac{1}{4}$ inch to 1 inch. $\frac{3}{16}$ inch 10*s.* per ton, and $\frac{1}{8}$ inch 30*s.* per ton extra.

Sketches, 20*s.* per ton. Curved sketches, 40*s.* per ton. 4 inch taper allowed before counting sketch.

*Guarantee.*—In case of serious defect, or error in dimensions, a plate will be replaced, and on receipt of the rejected one the amount originally charged will be credited. Dimensions will be worked to as nearly as practicable, but absolute exactness must not be expected. No further liability is undertaken by sellers except by special contract.

*Stoppage of Works.*—Should the works of the makers or buyers be stopped by a strike, or by accident to machinery or buildings, current contracts to be suspended during such interruption, but not to be thereby cancelled.

—*Fox, Head & Co.*

### 210. Deflection and Camber.

*Deflection* is the displacement of any point in a loaded beam from its position when the beam is unloaded.

*Camber* is an upward curvature, similar and equal to the maximum calculated deflection given to a beam or girder or some line in it in order to ensure its horizontality when fully loaded.

### 211. Deflection.

Radius of curvature of neutral axis of a beam at any section when under transverse stress

$$= \frac{E\,I}{M}.$$

### 212. Radius of Curvature

is the radius of the circle coinciding most nearly with a curved line or portion of one.

*Curvature* is the reciprocal of this radius. Thus, if radius be 100 feet, curvature is $\frac{1}{100}$. If radius alters further on to 120 feet, the change of curvature will be $\frac{1}{100} - \frac{1}{120} = \frac{1}{600}$.

The curvature of a circle is inversely proportional to its radius, and is measured by the fraction $\frac{1}{\text{radius}}$.

—*Goodeve.*

### 213. Deflection of Solid Beams.

$\Delta$ = deflection in inches.
$l$ = length in feet.
$b$ = breadth in inches.
$d$ = depth in inches.
W = load in cwts. in centre.

$c$ = constant =

| | | | |
|---|---|---|---|
| Cast steel | 650 | Quebec oak | 40 |
| Wrought iron | 550 | Fir and deal | 33 |
| Cast iron | 330 | Dantzic oak | 27 |
| Teak | 50 | Pitch pine | 25 |

Rectangular beam:

$$\Delta = \frac{l^3 W}{b\, d^3\, c}, \qquad W = \frac{\Delta\, b\, d^3\, c}{l^3},$$

$$b = \frac{l^3 W}{d^3\, \Delta\, c}, \qquad d = \sqrt[3]{\frac{l^3 W}{\Delta\, b\, c}}, \qquad b\, d^3 = \frac{l^3 W}{\Delta\, c}.$$

Square beam, side $= \sqrt[4]{\dfrac{l^3 W}{\Delta\, c}}$.

Cylindrical beam, diameter $= \sqrt[4]{\dfrac{l^3 W}{\Delta\, c}} \times 1{\cdot}7$.

If load be uniformly distributed, deflection $= \frac{5}{8}\,\Delta$.

Cantilever with distributed load $= \Delta\, 6$.

Cantilever loaded at end $= \Delta\, 16$.

Safe deflection in timber $= \frac{1}{480}$ length, or $\frac{1}{40}$ inch per foot span.

214. Coefficients for Deflection—Rectangular Beams.

| $\Delta =$ | | $\delta =$ | |
|---|---|---|---|
| Wrought iron | ·000002 | Fixed one end, loaded the other | 128 |
| Cast iron | ·000003 | „ load distributed | 48 |
| Steel | ·0000016 | Supported ends, load central | 8 |
| Oak | ·0000375 | „ load distributed | 5 |
| Ash | .. | Fixed both ends, load central | 2 |
| Fir | .. | „ load distributed | 1 |

$$\text{Deflection} = \frac{W \text{ lbs.} \times l^3 \text{ feet} \times \delta \times \Delta}{b \text{ inches} \times d^3 \text{ inches}}.$$

General formula for beams of uniform section, fixed one end, loaded the other, deflection $\Delta = \dfrac{W\, l^3}{3\, E\, I}$.

215. Coefficients of Reaction for Deflection.

| | | *Box.* | *Unwin.* |
|---|---|---|---|
| Fixed one end, loaded the other | K = | 32 | 16 |
| „ „ load distributed | = | 12 | 6 |
| Supported both ends, load central | = | 1 | 1 |
| „ „ load distributed | = | $\frac{5}{8}$ | $\frac{5}{8}$ |
| Fixed both ends, load central | = | $\frac{2}{3}$ | .. |
| „ „ load distributed | = | $\frac{5}{12}$ | .. |

## 216. Approximate Deflection of Wrought-Iron Flanged Girders

of uniform strength, supported at both ends, and carrying uniformly distributed load. Stress allowed = 5 tons per sq. inch tension, 4 tons per sq. inch compression.

$s$ = span in feet.
$d$ = mean depth in inches.
D = deflection in inches in centre.

$$D = \frac{\cdot 0144\, s^2}{d}.$$

If depth = $\frac{1}{10}$ span, D = $\cdot 012\, s$; $\frac{1}{12} = \cdot 0144\, s$; $\frac{1}{15} = \cdot 018\, s$.

## 217. Deflection of Girders.

In girders with parallel flanges of uniform strength, the deflection produces a circular curve, the amount of deflection varies directly as the load × the sum of the areas of both flanges × the cube of the length, and inversely as the area of top flange × area of bottom flange × depth of web squared, or

$$\Delta = \frac{W \times (a_t + a_b) \times l^3}{a_t \times a_b \times d^2} \times c.$$

| $c$ = | Wrought iron. | Cast iron. |
|---|---|---|
| Load centre | ·016 | ·025 |
| Load distributed | ·01 | ·018 |

L = span in inches.
W = load tons distributed ends supported.
I = moment of inertia.
E = modulus of elasticity in lbs. per square inch.
S = stress allowed in tons per square inch.
$\delta$ = deflection in inches.

For girder of uniform section:

$$\delta = \frac{5\, W L^3}{384\, E I}.$$

For girder of uniform strength:

$$\delta = \frac{S L^2}{4 E D}.$$

*Common Rule.*—Girders to be constructed with a camber of $\frac{1}{4}$ to $\frac{1}{2}$ inch per 10 feet of span, to allow for deflection when loaded.

Feet span × ·005 to ·0075 = safe deflection in inches under ordinary loads.

Feet span × ·02 to ·03 = safe deflection in inches under special loads.

American practice. Feet span × ·01 = safe deflection in inches after permanent set.

Board of Trade allows $\frac{3}{4}$ inch per 100 feet span ($= \frac{1}{1600}$ = ·0075) for deflection caused by maximum rolling load beyond the deflection due to maximum dead load.

## 218. Deflection Tests.

Two main girders 60 feet span erected in yard with cross girders and bearing for railway viaduct. Weight complete, one span with temporary timber, 22 tons.

| | | | | |
|---|---|---|---|---|
| Deflection in centre with | 30 tons distributed | | = | ·32 in. |
| „ „ | 60 | „ | = | ·685 „ |
| „ „ | 90 | „ | = | 1·085 „ |
| „ „ | 121·5 | „ | = | 1·53 „ |
| „ „ | do. and 10 tons centre | | = | 1·73 „ |
| „ „ | loads removed | | = | ·47 „ |

## 219. Load on Bridges.

Assuming deflection to vary directly as load, the WORK done by gradually applied load = load lbs. × $\frac{1}{2}$ deflection feet, but with suddenly applied load = load lbs. × deflection feet, because it drops through the whole distance, and the deflection being double that due to the same load gradually applied, the WORK will be quadrupled. A rolling load on a girder is not quite a suddenly applied load, but somewhere

between that and a dead load. The stress in a given beam varies as the deflection.

| Load. | Ratio of Deflection or Maximum Stress. |
|---|---|
| Dead, gradually applied . . . . | 5 |
| Live, rolling on . . . . . | 8 |
| „ suddenly applied . . . . | 10 |

### 220. Deflection of Beams under Impact.

P = weight of load falling upon centre of beam.
$h$ = vertical height of fall to surface of unstrained beam.
$d$ = static deflection due to P.
D = actual dynamic deflection due to impact of falling load.
W = weight of beam.
$m$ = constant depending upon ratio of P to W.

$$m = \frac{35\,P}{35\,P + 17\,W}.$$

$$D = d + \sqrt{2\,m\,h\,d + d^2}.$$

In the case of a suddenly applied load, $h = 0$ and $D = 2\,d$.

—*Merriman's 'Mechanics of Materials.'*

### 221. Strength of Flat Carriage Springs.

For spiral springs, see Art. 484 *et seq.*

E = modulus of elasticity for spring steel = 16,000 tons.
$e$ = ultimate extension of fibre, say ·0025.
S = ultimate stress, tons per square inch = E $e$ = 40.
L = half length of spring from buckle in inches.
$b$ = breadth of plate in inches.
$n$ = number of plates.
W = total load on spring in tons.
$d$ = length of offset $= \frac{L}{n}$.
$v$ = deflection of spring in inches per ton of load.

$V$ = working deflection $= vW$.

$r$ = radius of curve of camber $= \frac{E\,t}{2\,S}$ = approx. $200\,t$.

Safe working load of spring in tons $= \frac{S\,b\,t^2\,n}{3\,L}$.

$$v = \frac{4\,L^3}{E\,b\,t^3\,n}, \qquad n = \frac{L\,W}{13 \cdot 3\,b\,t^2}.$$

Half span of spring from buckle $= \sqrt{(2\,r - V)\,v}$.
The deflection varies directly as the load.

Another rule:

$d$ = deflection in sixteenths of an inch per ton of load.
$s$ = span in inches.
$b$ = breadth in inches.
$t$ = thickness of leaves in sixteenths of an inch.
$n$ = number of leaves.

$$d = 1 \cdot 64 \times \frac{s^3}{b\,(n\,.\,t^3)}.$$

## 222. Notes on Torsion and Shafting.

Torsion is measured by the load acting at 1 foot radius which is required to fracture a specimen 1 inch diameter.

Strength varies as $\frac{d^3}{r}$, stiffness as $\frac{d^4}{l}$.

To run smoothly, long shafting must not twist more than 1° in 10 feet under maximum load.

Long shafts are not designed in strict accordance with rule, as they would then be tapered from driving end, involving extra assortment of driving pulleys.

Every alteration in diameter of a shaft, unless made at a coupling, must be made gradually by means of a curve at the junction of the two diameters, or a long taper.

Factor of safety, long shafts less than $4\frac{1}{2}$ inches diameter $= \frac{1}{10}$; short shafts and all over $4\frac{1}{2}$ inches diameter $= \frac{1}{6}$.

Distance apart of supports in feet $= 5 \sqrt[3]{d^2}$. Friction of ordinary shop shafting is about 1 horse-power per 100 feet.

### 223. Approximate Strength of Shafting.

The safe load on wrought-iron shaft 1 inch diameter at 1 foot radius is 100 lbs.

$$\therefore \quad W = 100 \frac{d^3 \text{ ins.}}{\text{lev. ft.}}, \quad d = \sqrt[3]{\frac{W \times \text{lev.}}{100}}, \quad \text{lev.} = \frac{100\, d^3}{W}.$$

### 224. Ultimate Torsional Strength of Various Metals.

Round bars 1 inch diameter, load applied at 1 foot radius.

| | | |
|---|---|---|
| Cast steel . . . | average | 1500 lbs. |
| Mild steel . . . | „ | 1200 „ |
| Wrought iron . . | „ | 800 „ |
| Cast iron . . . | „ | 700 „ |
| Wrought copper . . | „ | 400 „ |

These, although average test loads, are rather higher than are usually adopted in practical calculations. See section on calculation of engine shafts.

### 225. Torsional Modulus of Elasticity.

The torsional modulus of elasticity is about 46 per cent. of the modulus in tension, and nearly constant for all classes of material substances.—*Platt and Hayward.*

### 226. Transmission of Power by Shafting.

Strength of shaft to transmit power depends upon velocity; thus, shaft able to transmit 20 horse-power at 60 revolutions is sufficient for 60 horse-power at 180 revolutions. The explanation is, that the actual strain is the same in each case, the increase in horse-power being due to the increase in speed only. Power consists of pressure and velocity, and varies directly as the amount of each.

### 227. Formula for Strength of Shafting.

$W$ = B.W. in lbs. at 1 foot radius of shaft 1 inch diam.
$c$ = coefficient of safety = $\frac{1}{6}$ to $\frac{1}{10}$.
$d$ = diameter of wrought-iron shaft in inches.
$l$ = leverage in feet.
$s$ = strain in lbs. at circumference of wheel.

$$d = \sqrt[3]{\frac{s\,l}{W\,c}}. \qquad s = \frac{W\,d^3}{l} \times c.$$

### 228. Molesworth's Formula for Wrought-Iron Shafting.

$D$ = diameter of shaft in inches.

$$K = \begin{cases} 320 \text{ for crank shafts and prime movers.} \\ 200 \text{ for second motion shafts.} \\ 100 \text{ for ordinary shafting (but never less than 80).} \end{cases}$$

$H$ = actual horse-power to be transmitted.
$n$ = number of revolutions per minute.
$l$ = leverage in feet.
$f$ = force applied in lbs. at circumference of wheel.

$$H = \frac{2\,\pi\,l\,n\,f}{33000}. \qquad H = \frac{D^3\,n}{K}. \qquad f = \frac{D^3}{2\,\pi\,l} \times K.$$

$$f = \frac{33000\,H}{2\,\pi\,l\,n}. \qquad D = \sqrt[3]{\frac{H}{n} \times K}.$$

$$D = \sqrt{\frac{2\,\pi\,l\,f}{33000} \times K}.$$

### 229. Diameter of Coupling Bolts in Screw Shafts.

$D$ = diameter of shaft.
$d$ = " bolts.
$n$ = number of bolts.
$r$ = radius of pitch circle for bolts.

All in inches.

$$d = \cdot 577 \times \sqrt{\frac{D^3}{n\,r}}.$$

### 230. Proportions of Solid Wrought-Iron Flange Coupling on Screw Shaft.

Let $d$ = diameter of shaft. Then there should be eight bolts, each $\frac{1}{4}\,d$ in diameter, the diameter of circle passing through the centres being $1\frac{1}{2}\,d$. The flanges should be $2\,d$ in diameter and $\frac{1}{4}\,d$ thick.—*Unwin.*

Note.—Six bolts are commonly used, up to 6 inches diameter of shaft.

For marine crank shaft, web of throw = $\frac{3}{4}\,d$ thick, pin = $d$ dameter, area of bolts (total) = area of shaft.

### 231. Transverse Strength of Shafts.

Load distributed on wrought-iron crank pin or overhanging journal in lbs., $c = 1200$.

Ditto, concentrated on shaft supported at ends, $c = 2400$.

Ditto, distributed „ „ $c = 4800$.

$$\text{Safe load} = c\,\frac{d^3}{l}. \qquad d = \sqrt[3]{\frac{W\,l}{c}}.$$

Forces may be taken to act at the centres of journals in cases where supports are not contiguous to journals.

### 232. Proportions of Bolts, Nuts and Washers in Carpentry.

| | | | |
|---|---|---|---|
| Thickness of nut . . . . | = | 1 | diameter of bolt. |
| „ head . . . . | = | $\frac{3}{4}$ | „ |
| Diameter of head or nut over sides . | = | $1\frac{5}{8}$ | „ |
| Side of square washer for fir . . | = | $3\frac{1}{2}$ | „ |
| „ „ oak . . | = | $2\frac{1}{2}$ | „ |
| Thickness of washer . . . | = | $\frac{1}{3}$ | „ |

When the nuts are let in flush in fir, the washers should be the same size as for oak.

## 233. Strength of Bolts.

Bolts in machinery subject to varying loads should not be strained to more than 2 tons per square inch of minimum section. A bolt 1 inch diameter, being ·84 diameter, or ·55 area at bottom of thread, will take not more than (say) 2000 lbs., including initial strain in screwing up.

Let $d$ = outside diameter of thread in inches; $2000\ d^2$ = safe load in lbs. for 1 inch bolts and upwards; $2000\ d^3$ = safe load in lbs. for 1-inch bolts and under.

The ordinary force used in screwing up bolts is liable to break a $\frac{3}{8}$-inch bolt and seriously injure a $\frac{1}{2}$-inch bolt; hence bolts for joints requiring to be tightly screwed up should not be less than $\frac{3}{4}$ inch in diameter.

The approximate area of Whitworth bolts at bottom of thread = diameter of bolt in $\frac{1}{8}$ths inch × (diameter in $\frac{1}{8}$ths inch − 1) ÷ 100.

For proportions of Whitworth's Standard see Art. 692.

## 234. Strength of Bolts (Unwin).

| | Per sq. inch net area. |
|---|---|
| (*a*) Bolts not requiring to be tightened before load is applied, also (*c*) when cylinder exceeds 60 inches diameter . . . . | Safe load = 6000 lbs. |
| (*b*) Bolts accurately fitted and requiring to be tightened moderately, also (*c*) when cylinder exceeds 20 inches diameter . . . . | „ = 4000 „ |
| (*c*) Bolts used to draw joints steam-tight and resist the pressure in addition . . . . . | „ = 2000 „ |

## 235. Flange Studs of Steam Cylinders.

For small cylinders allow 2700 lbs. per sq. inch of net section (minimum diameter of bolts $\frac{5}{8}$ inch).

For large cylinders (over 18 inches diameter) allow 3000 lbs. ditto ditto.

### 236. To Secure Check or Lock Nuts.

Put on check nut ($\frac{1}{2}$ diameter of bolt in thickness), screw up as tight against flange or work as an ordinary nut would be screwed under the circumstances, then put on ordinary thick nut (1 diameter thick), screw it up with the same force and hold on to it with the spanner. Then with a thin spanner reverse the check nut against the other as far as it will go with about the same pressure as before. The check nut has then only the screwing up force to resist, while the thick nut has in addition the strain which may be brought upon it by load or vibration.

### 237. Check Nuts.

. . . . This loosening of a nut can be prevented by adding another nut, which must be screwed hard down upon the first to increase the pressure upon the thread.—*Willis*' '*Mechanism*.'

*Note.*—As described here, the second nut would only be equivalent to thickening the first nut, and would be useless as a check, unless tightened up to the limits of abrasion.

### 238. Pressure on Bearing Area in Holes.

The pressure of a pin in an eye, or a bolt in a hole, or a rivet in a plate, resisting a side pull or shearing stress, should be limited to the safe pressure on bearing surface. The maximum pressure (P) per sq. inch, assuming the bearing surface to be $\frac{1}{4}$th of the circumference, will be $= P/\cdot 7854\ d\ t$, where $P =$ total pressure, $d =$ diameter, $t =$ thickness.

*Example.* — $1\frac{1}{2}$-inch pin, load 3 tons, thickness $\frac{3}{4}$ inch, $P = 3/\cdot 7854 \times 1\cdot 5 \times \cdot 75 = 3\cdot 4$ tons per sq. inch. Or if required to limit pressure on bearing area to say 2 tons per sq. inch, then $1\frac{1}{2}$-inch pin with 3 tons load will require thickness in eye of $t = 3/\cdot 7854 \times 1\cdot 5 \times 2 = 1\cdot 28$ inches.

# SECTION IV.

# PATTERN-MAKING, MOULDING AND FOUNDING.

## 239. Pattern-making.

Small patterns made of mahogany or New Zealand pine. Larger patterns made of white or yellow pine. Metal patterns used where a great number of similar castings are required. Wood patterns coated with varnish, to prevent distortion from damp sand, black for general body, red for ends of prints or cores, and yellow for machined faces. Some are one colour only.

Patterns should have rounded edges, and filleted angles wherever possible. The thickness of metal throughout a casting should be as uniform as possible, sudden changes of direction being avoided. Sharp angles in a casting are always weak; the crystals while cooling arrange themselves perpendicularly to the surface, and hence at a sharp turn there is an awkward junction, which becomes a source of weakness. Sufficient taper, say $\frac{1}{8}$ inch per foot, must be given to draw out of the sand, and allowance made for knocking to loosen in mould.

Holes for bolts, &c., may be "cast in," or "cored out"; when cast in, sufficient taper must be given to draw the pattern, and small side of hole must be large enough for bolt; when cored out a print must be put on one or both ends to form support for core. Prints should project from $\frac{1}{2}$ inch to 3 inches, according to weight of core to be carried. Heel cores are made when the print is at any distance from the parting.

### 240. Black Varnish for Patterns.

Lampblack 1 part, shellac 5 parts, methylated finish 16 parts, all by weight. First coat rubbed over with glass paper when dry and second coat then laid on.

### 241. Weight of Casting from Pattern.

Multiply weight of deal pattern by—17 for cast iron, 18 for brass, 19 for copper, 25 for lead.—*Hurst.*

### 242. Allowance for Machining.

Average on iron castings = $\frac{1}{8}$ inch, brass $\frac{1}{16}$ inch. Castings likely to twist in cooling require more, very small castings require less. In small cylinders $\frac{1}{4}$ inch in the diameter is sufficient, cylinders over 4 feet diameter say $\frac{3}{8}$ inch.

### 243. Moulding in Foundry.

*Green-sand Moulding.*—Used for light iron castings, fire-bars, rough machine castings, &c. The ordinary damp sand of the foundry is used in iron boxes or "flasks" for receiving impression from "patterns," the hollow parts being formed of baked sand "cores." Long cores are supported by "chaplets," small and complicated cores are made of "loam."

*Dry-sand Moulding.*—Used for ornamental ironwork, important machine castings, and for casting in brass. The sand consists of fresh sand mixed with loam which has been used, or of fresh sand only. When finished, the moulds are dried for several hours. "Blackening" prevents sand melting.

*Loam Moulding.*—Used for steam cylinders, bent pipes and complicated work. The mould is often built up with-

out patterns, and consists of brickwork coated with loam and "swept" to required shape by a "loam board." Long straight cores are formed of iron pipe with haybands twisted on to hold the loam, and other cores of loam strengthened by bent "core-irons." The loam is common brick-clay mixed with horse-dung, cow-hair, sand, &c. "Runners" and "gates" are openings in the sand to let the metal into the mould; "vents" are openings to let the gases out, formed by pricking the sand.

### 244. Sand for Moulding.

*Moulding Sand* consists of 93 to 96 per cent. of sharp sand and 3 to 6 per cent. of clay. Quality varies for different castings; the smaller the castings, the more clay the sand may contain; heavy castings require poorer and coarser sand. Coal and coke are used to make the sand more porous; this makes the castings rougher, but by giving free vent to the gases makes them sounder. Moulding sand after use is "screened" and wetted before being used again.

*Parting Sand* is the burnt sand scraped off castings, and is used to facilitate the division of the upper and lower boxes in moulding.

*Core Sand* consists of 90 per cent. sharp sand and 10 per cent. of clay, and should be used fresh.

### 245. Foundry Drying Stove.

Brick chamber of three sides with arched top shut with close iron doors on fourth side. Size about 10 feet × 10 feet × 7 feet high. Fire-place on one side, flue near ground on opposite side to spread the heat and carry off the moisture, fire fed through a door on outside. Iron shelves on walls for drying small cores and boxes. Rails run from crane into drying stove, so that large moulds may be wheeled in. Stoves of various sizes in large foundry, the larger ones only used when required for very large moulds.

## 246. Notes on Moulding and Casting.

Keep most important side of casting at the bottom to ensure density in the metal, as tension flange of girder, &c. Make ample provision for escape of gases by pricking the mould, providing vents, &c. Support long cores and stiffen with core irons to prevent displacement by molten metal. Knock pattern slightly before drawing from mould to enable it to be lifted without breaking the sand. Provide sufficient number of gates to ensure the mould being completely filled with metal. Allow ample head on important castings to cut off all "sullage" or porous and honeycombed portion. The molten metal should be stirred through the gates with an iron rod, called a "feeding rod," to agitate it and cause it to fill angles and corners, more metal being added if required. Directly the metal is run into the mould the gases should be fired to prevent explosion. Metal usually run in afternoon, allowing all night for castings to cool.

## 247. Cleaning Castings.

Moulds taken apart and sand removed as soon as castings have set, castings taken out with tongs and left to cool, time varying according to weight and mass. Gates, or "gits," and partings, or "fins," broken off, and heavy or hard cores removed in foundry before casting is cold. Projections removed in cleaning or fettling shop with chisel, sharp hammer, or worn-out file, and casting well brushed with steel wire brush. Grindstones or emery wheels used in some shops instead of chisel and file. Blow-holes stopped with black putty, cement, or lead, and castings painted with black wash. Badly honeycombed castings thrown on the scrap heap. The scrap averages 25 per cent. of the castings, less on large work.

## 248. Classification of Iron Ores.

Mr. Truran classifies the ores of Great Britain into four great divisions, thus :—

A. The argillaceous ores of the coal formations, having clay, but sometimes silica, as the chief impurity.

B. The carbonaceous ores of the coal formations, distinguished by their large percentage of carbon.

C. The calcareous or spathic ores, or the sparry carbonates of iron, having lime as their chief earthy admixture.

D. The siliceous ores, having silica as their predominating earth. This class is subdivided into the red and brown hæmatites, the ores of the oolitic formation, the white carbonates, and the magnetic oxides.

## 249. Charges Employed at Dowlais for Different Kinds of Pig Iron.

| — | Foundry Pig. | White Forge Pig. | Common Forge Pig. |
|---|---|---|---|
| | cwt. | cwt. | cwt. |
| Calcined "mine" (fresh ore) . | 48 | 28 | .. |
| Red hæmatite ore . . . . | .. | 10 | 16 |
| Forge and refinery cinder . | .. | 10 | 25 |
| Limestone . . . . . | 17 | 14 | 16 |
| Coal . . . . . . | 50 | 42 | 36 |
| Weekly make . . | 130 tons | 170 tons | 190 tons |

## 250. Analyses of Pig Iron.

| | Per cent. |
|---|---|
| Carbon, partly combined and partly in a graphitic form . . . . | 2·3 to 5·5 |
| Silicon . . . . . . . | 0·13 „ 5·7 |
| Manganese . . . . . . | 0·0 „ 7·6 |
| Sulphur . . . . . . . | 0·0 „ 0·87 |
| Phosphorus . . . . . . | 0·0 „ 1·66 |

### 251. Foundry Pig.

No. 1 Pig is chiefly used in the foundry. Colour dark grey, crystals large and leafy, carbon in form of graphite. Very soft, melts very fluid, but being coarse-grained, will not give a sharp impression. Cools slowly. For fine castings the presence of a little phosphorus is advantageous: the grain is finer, the iron a lighter colour, and the impressions sharper. Used for small castings, hollow ware, small machinery, &c.

No. 2 Pig, grey and mottled in colour. Carbon partly combined. Used for large castings in dry sand or loam. Melts fluid, is tough, close texture, fills the mould well, more free from impurities than No. 1. Heavy machine castings made from No. 2, or various mixtures of 1, 2 and 3.

No. 3 Pig, hard and white, used for mixing. Carbon all chemically combined.

### 252. Mixtures of Pig Iron.

Mixture recommended for girders, &c., where rigidity and strength are required:—

| | |
|---|---|
| Lowmoor, Yorkshire, No. 3 . . | 30 per cent. |
| Blaina or Yorkshire No. 2 . . | 25 „ |
| Shropshire or Derbyshire No. 3 . . | 25 „ |
| Good old cast scrap . . . . . | 20 „ |
| | 100 |

—*Fairbairn.*

Mixture for steam cylinders, strong and close grained.

| | |
|---|---|
| No. 5 charcoal pig . . . . | 8 parts. |
| Scotch pig . . . . . . | 10 „ |
| Good cast scrap . . . . . | 10 „ |

For the same, where greater hardness is required.

| | |
|---|---|
| No. 5 charcoal pig . . . . | 2 parts. |
| Scotch pig . . . . . | 4 „ |
| Good cast scrap . . . . | 30 „ |

Piston rings should be of softer metal than the cylinders.

—*Rigg's 'Steam Engine.'*

## 253. Melting Metal for Castings.

*Crucibles* are sometimes used for melting iron for trinkets and small goods. The best castings, whether iron, bronze, or other metal, for machine frames, bells, statues, &c., are made from a *reverberatory furnace*, run directly from the furnace in dry sand ditches to the mould. The *cupola* has the advantage of melting iron cheaper than any other furnace; where strength is unimportant, it is the best method.

## 254. Contraction of Metals in Cooling.

| Metal. | Contraction. | |
|---|---|---|
| | In Fractions of Linear Dimensions. | In Parts of an Inch per Foot of Linear Dimensions. |
| Cast iron . . . . . | $\frac{1}{96}$ | $\frac{1}{8}$ |
| Gun metal . . . . . | $\frac{1}{72}$ | $\frac{1}{6}$ |
| Yellow brass . . . . . | $\frac{1}{64}$ | $\frac{3}{16}$ |
| Copper . . . . . . | $\frac{1}{60}$ | $\frac{1}{5}$ |
| Zinc and tin . . . . . | $\frac{1}{48}$ | $\frac{1}{4}$ |
| Lead . . . . . . . | $\frac{1}{39}$ | $\frac{5}{16}$ |

## 255. Contraction of Castings.

Heavy pipes . . . . = $\frac{1}{8}$ inch per foot.
Girders, beams, &c. . . = $\frac{1}{8}$ „ in 14 inches.

| | | | | |
|---|---|---|---|---|
| Engine beams<br>Connecting rods | = | $\frac{1}{8}$ inch in 16 inches. | | |
| Large cylinders, say 70 inches diameter × 10 feet stroke, the contraction of diameter | = | $\frac{3}{8}$ | „ | at top. |
| | = | $\frac{1}{2}$ | „ | at bottom. |
| Ditto in length | = | $\frac{1}{8}$ | „ | in 16 iches. |
| Small narrow wheels, about | = | $\frac{1}{25}$ | „ | per foot diam. |
| Large heavy wheels | = | $\frac{1}{10}$ | „ | or more „ |
| Thin brass | = | $\frac{1}{8}$ | „ | in 9 inches. |
| Thick brass | = | $\frac{1}{8}$ | „ | in 10 inches. |
| Gun-metal rods | = | $\frac{1}{8}$ | „ | in 9 inches. |
| Zinc | = | $\frac{5}{16}$ inch per foot. | | |
| Copper | = | $\frac{3}{16}$ | „ | „ |
| Bismuth | = | $\frac{5}{32}$ | „ | „ |
| Tin and lead, each | = | $\frac{1}{4}$ | „ | „ |

Pattern-makers commonly allow for iron castings $\frac{1}{8}$ inch per foot, and for brass castings $\frac{3}{16}$ inch per foot. The apparent contraction varies considerably according to the amount of "rapping" the pattern receives in the sand.

### 256. Expansion of Castings.

Some castings, owing to their form, expand in one direction while contracting in another. This is known to pattern-makers as "compression." It is usually a contraction of surface area and expansion in thickness, the expansion taking place in the direction in which the heat most readily radiates, and being chiefly noticeable in tram plates and such like forms.

### 257. Bronze and Brass Castings.

Melted in crucibles, wasting prevented by covering surface with mixture of potash, soda and charcoal powder. Copper melted first, then tin, zinc, or antimony, then cover-

ing applied. Zinc is best added in form of brass, calculating the copper contained. Large strong castings require the metal exposed to fire in fluid state 8 or 10 hours, proof taken by small ladle and broken when cool, judged by crystallisation, and copper or tin added as required. Before casting, bronze is well stirred with heated iron rods. Brass made by melting together copper scraps, crude zinc or spelter, and charcoal powder, remelted for casting. About 7 lbs. per cwt. is allowed for waste.

## SECTION V.

# FORGING, WELDING, RIVETING, Etc.

### 258. Forging.

Wrought-iron at a red heat may be hammered into various shapes, called "forging." When a piece is drawn down smaller it is called "swaging"; if jumped up thicker, it is called "upsetting." Common iron is not suitable for forging, as the scale or slag in it causes cracks. Double and treble best Staffordshire and ordinary Yorkshire are suitable. The best Yorkshire is used for flanging and difficult forgings; charcoal iron for light and complicated work.

Steel may be forged gradually at a low heat. The greater the proportion of carbon contained, the greater the difficulty of forging. All forging should proceed by easy stages, and care be taken not to burn the iron or steel. Large pieces have a rod or "porter" welded to them for convenience in handling by a crane.

### 259. Welding

is the process of joining two pieces of wrought iron or steel by heating, and hammering them together. To weld iron the pieces must be brought to a white heat, and the scale swept off before they are put together. Steel requires a much lower heat, and the surfaces should be sprinkled with sand, borax, or silicate of soda, to aid the surface fusion. Borate of soda similarly aids the surface fusion of spelter in hard soldering. The welding temperature depends upon the amount of carbon contained: hence the extra difficulty of welding two pieces of different composition. Mild steel ap-

proaches wrought iron in its welding qualities. Steel faces may with care be welded on to iron tools; shear steel is generally used for this purpose. Average loss of strength in weld is 15 to 20 per cent.

In electric welding, a current is passed through the abutting edges which are pressed together, surface-fusion is almost immediately produced, and the junction commences at the centre, proceeding uniformly to the outside. This weld is said to be of equal strength with the solid material, but the loss probably reaches 10 per cent.

### 260. Tempering.

Steel when heated to a cherry red, and suddenly cooled in water or oil, is rendered very hard. Some suppose that the carbon is caused to take the crystalline or diamond form. For tempering the hardened steel a portion is brightened with a piece of broken grindstone, and then reheated until the film of oxide formed on the surface shows the requisite temperature; it is then quenched in water, and the hardness is found to be "let down" to the "temper" required. Tempering was formerly considered to be the only true test of steel.

### 261. Colours corresponding to Temperature.

| | Deg. F. |
|---|---|
| Lowest red heat visible in the dark | 635 |
| Faint red | 960 |
| Dull red | 1290 |
| Brilliant red | 1470 |
| Cherry red | 1650 |
| Bright cherry red | 1830 |
| Orange | 2010 |
| Bright orange | 2190 |
| White heat | 2370 |
| Bright white heat | 2550 |
| Dazzling white heat | 2730 |
| Welding or scintillating heat | 2800 |

—*Becquerel, Pouillet, &c.*

## 262. Tempering Steel.

Colours produced at various Temperatures, and Alloys Fusible at same.

| Colour of Film. | Temp. F. | Nature of Tool. | Lead. | Tin. |
|---|---|---|---|---|
| None . . . . . . | ° 400 | . . . . . . . . . | 22 | 16 |
| Very pale yellow straw . . . | 430 | Lancets and turning-tools for cast steel . | 30 | 16 |
| A shade of darker yellow . . | 450 | Razors and ditto . . . . . . . | 34 | 16 |
| Darker straw yellow . . . | 470 | Penknives, turning-tools for iron . . . | 42 | 16 |
| Orange yellow . . . . | 490 | Cold chisels, drills, screw taps, wood tools . | 56 | 16 |
| Brownish yellow . . . . | 500 | Hatchets, plane-irons, chipping-chisels, saws for iron, tools for working granite, turning-tools for brass . . . . . | 66 | 16 |
| Yellow tinged with purple . . | 520 | | 100 | 16 |
| Light purple . . . . . | 530 | Swords, ordinary springs, tools for cutting sandstone . . . . . . . | 120 | 16 |
| Dark purple . . . . . | 550 | | 192 | 16 |
| Dark blue . . . . . | 570 | Small saws, watch-springs . . . . | .. | .. |
| Pale blue . . . . . | 600 | Large saws, pit and hand saws . . . | .. | .. |
| Pale blue with tinge of green | 620 | Too soft for steel instruments . . . | All | 0 |
| Grey . . . . . . | 750 | | | |

From experiments made by Wedgwood, there is reason to believe that all bodies susceptible of the requisite temperature become red hot at exactly the same point. Wood and most liquids are dissipated before their temperature can be sufficiently raised to be luminous. Gases do not become luminous, even at a much higher temperature than suffices for solids.

### 263. Notes on Riveted Joints.

Hard wrought iron is weakened from 15 to 30 per cent. by punching. In punched plates the small sides of the holes should come together. Drilled holes should have the edges chamfered.

The tension in a rivet may be estimated at 21,000 lbs. per square inch of its section. Friction due to this tension would be about 7000 lbs. per square inch of rivet section.

The usual diameter of rivets in hand riveting varies from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch. In machine riveting they may be used up to $1\frac{1}{4}$ inch diameter.

Maximum efficiency of single riveted joint = $\frac{2}{3}$ strength of plate. Ordinary efficiency = $\frac{9}{16}$. Maximum efficiency of double riveted joint = $\frac{4}{5}$ strength of plate. Ordinary efficiency = $\frac{3}{4}$.

Pitch of rivets (for equal area of plate and rivet) =

$$\frac{\text{Sect. area of rivet} \times \text{effective No. of rows}}{\text{Thickness of plate}} + \text{diam. of rivet.}$$

$$\text{Chain riveting} = \begin{matrix} \times & \times & \times & \times \\ \times & \times & \times & \times \end{matrix}.$$

$$\text{Zigzag, reeled, or staggered} = \begin{matrix} \times & & \times & & \times & \\ & \times & & \times & & \times \end{matrix}.$$

To rivet by hand requires a minimum of 1 diameter, and by machine $1\frac{1}{8}$ diameter of rivet to form head. Length of rivet for good head = thickness of plates passed through + $1\frac{1}{2}$ diameter + $\frac{1}{16}$ inch for each joint. Rivets 6 to 8 diameters long often draw off their heads. Rivets are

usually $\frac{1}{16}$ inch smaller than hole, generally $\frac{3}{4}$-inch iron in $\frac{13}{16}$ inch hole, but may be $\frac{11}{16}$-inch iron in $\frac{3}{4}$-inch hole. Countersunk rivets 60°, countersunk $\frac{2}{3}$ diameter of rivet.

A rivet hole cannot be punched with its edge nearer the edge of the plate than its own diameter without risk of its bursting through. To this it is safe to add $\frac{1}{8}$ inch to $\frac{1}{4}$ inch on the plate as the size of rivet and thickness of plate increase. The edges of two holes cannot be nearer than 1 to $1\frac{1}{2}$ diameter without risk of the second hole distorting the first, or the two holes punching into one.

The efficiency of the bearing surface of rivets = 5 tons per square inch; thus a $\frac{7}{8}$-inch rivet in a $\frac{3}{4}$-inch plate $= \frac{7}{8} \times \frac{3}{4} \times 5 = 3 \cdot 3$ tons nearly.

18 rivets go to the "yard" for piecework, irrespective of the pitch.

## 264. Pressure to Close Rivets.

Experiment:—Cold riveting, $\frac{3}{8}$-inch rivets.

At 10,000 lbs. rivet swelled and filled hole without forming head.

At 20,000 lbs. head formed and plates slightly pinched.

At 30,000 lbs. rivet well made.

At 40,000 lbs. metal in plates round rivet began to stretch.

Therefore, approximately, $d$ in $\frac{1}{8}$ths$^2 \times 2$ = tons pressure required for cold riveting per sq. inch of rivet section, and $d$ in $\frac{1}{8}$ths$^2$ = tons pressure for hot riveting per sq. inch rivet section.

## 265. Machine Riveting for Boilers.

With $\frac{3}{4}$-inch rivets the closing pressure in riveting $\frac{3}{8}$-inch plates is 38 tons, $\frac{1}{2}$-inch plates 40 tons, and steel plates 45 tons. The cup must be left on until the rivet is black.

In hydraulic riveting the pressure on the cup head = 12,000 to 16,000 lbs. per square inch of surface.

### 266. Proportion of Rivet Diameter to Thickness of Plate.

In punching, the resistance of steel = $100^k$ per sq. cm.
 „ „ iron = 30 „

Punch $= 100 \times \frac{\pi d^2}{4}$, plate $= 30\,\pi\,d \times e$.

$$\therefore \quad d > \frac{30\,\pi\,d\,e}{100\,\frac{\pi\,d}{4}} = 1{\cdot}2\,e\,(e = \text{thickness});$$

but $d$ must be $< 3\,e$, or crushing by the pressure of the rivet on edge of plate will occur, hence the usual proportion of $d = 2\,e$. —*Planat.*

### 267. Riveting.

Heads $\cdot 66\,d \times 1{\cdot}66\,d$ with radius of $\cdot 86\,d$. Length to make this $= 1\,d$ (?), N = tension, $\omega$ = section, $t$ = temperature of heated rivet when closed, E = coefficient of elasticity, then

$$\frac{\mathrm{N}}{\omega} = \frac{7\,\mathrm{E}\,t}{11 \times 81{,}500},$$

N being the tension capable of producing a stretch equal to that by temperature $t$.

The tension is independent of the length, and varies solely as the closing temperature, which should not exceed 212° F. Adhesion due to this temperature $= 9{\cdot}4^k$ per sq. mm., and at 150° C. $= 14^k$. —*Planat.*

### 268. Single Riveting in Boiler or Tank Work.

$t$ = thickness of plates in inches.
$d$ = diameter of rivets „
$p$ = pitch „ „
$l$ = lap of plates „

$$d = t + \tfrac{5}{16}$$
$$p = 1{\cdot}6\,t + 1\tfrac{1}{4}$$
$$l = 3\,t + 1\tfrac{1}{8}$$

### 269. Rivets in Tie Bars and Diagonal Riveting generally.

Prof. Kennedy, in his 'Abstract of Results of Experiments on Riveted Joints,' as made by the Research Committee of the Inst. Mech. Eng., says, "It has been found that the net metal measured zigzag should be from 30 to 35 per cent. in excess of that measured straight across in order to ensure a straight fracture. This corresponds to a diagonal pitch of $\frac{2}{3}p + \frac{d}{3}$, if $p =$ the straight pitch and $d$ the diameter of the rivet hole."

### 270. Notes on Caulking.

Caulking consists of burring up the inner edge of the plates in a joint by means of a tool like a flat-ended chisel, to prevent leakage in boilers, tanks, &c.

Plates with rough sheared edges should be chipped even, to a slight bevel, before caulking.

Joints appearing at all open should be closed by a flogging hammer before caulking.

When the caulking is done on one side only, it should be upon the same side as the riveting. In best work the joints are caulked inside and out.

When the lap exceeds three times diameter of rivet the caulking is apt to open the joint, unless done very lightly.

### 271. Caulking Tools.

The caulking tool should be flat-ended and slightly bevelled, from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch thick $\times$ 1 inch to $1\frac{1}{4}$ inch wide, with one edge square, and the other rounded to prevent cutting into the plate.

The rounded edge should be held next to the plate the first time of going along the joint, called splitting the lap, and afterwards reversed.

The finished caulking should appear like a parallel groove about $\frac{1}{32}$-inch deep $\times$ $\frac{1}{8}$-inch wide in a $\frac{3}{8}$-inch plate.

## SECTION VI.

# WORKSHOP TOOLS AND GENERAL MACHINERY.

### 272. Object of Machines.

The object of machines is to change the direction of motion, or to regulate the distribution of power. They transmit energy and modify it in direction, intensity, or velocity, but they can neither create nor increase power. An *engine* transmitting energy from *natural forces* is called *a prime mover*, but is otherwise a machine.

The power of a machine is measured by the work which can be done in a given time.

*Machines are used for—*

1. Accumulating force upon a given point or object.
2. Increasing or decreasing velocity of motion.
3. Prolonging the action of a power.
4. Changing the direction of motion.
5. Reducing the time of labour.
6. Producing accuracy in work.

*The parts may be divided into—*

1. Receivers. 2. Communicators. 3. Operators.

*Motive Power may be derived from—*

1. Man and animals.
2. Fall of water.
3. Force of wind.
4. Descent of weights.
5. Action of springs.
6. Expansion of elastic fluids.
7. Electricity and magnetism.
8. Chemical reactions.

### 273. Machinery in Motion.

In engines or machines in motion, when the power exceeds the work the speed will be accelerated, unless prevented, until the resistance + the useful work = the power. When the resistance + the useful work exceeds the power, the speed will be retarded until a balance is again obtained. In the former case the inertia of the parts will absorb some of the power, and in the latter this power will be again given out as momentum.

Motion may be rectilinear or curvilinear—direct or reciprocating—uniform or variable (uniformly accelerated, uniformly retarded, or irregular).

### 274. Useful Work and Efficiency.

*Useful work* of a machine is that performed in producing the effect for which the machine is designed.

*Lost work* is that performed in producing other effects, as overcoming friction, loss by leakage, &c.

The *power* of a machine is the energy exerted, and the *effect* the useful work performed, in some interval of time of definite length.

The *efficiency* [or *mechanical efficiency*] of a machine is a fraction expressing the ratio of the useful work to the whole work performed or energy expended. This ratio is also called the *modulus* or *coefficient* of the machine.

The *counter-efficiency* is the reciprocal of the efficiency, and is the ratio in which the energy expended is greater than the useful work. —*Rankine's 'Applied Mechanics.'*

### 275. Economical Working of Machines.

In every machine a certain rate of work develops the maximum efficiency. A medium load with a fair velocity produces more units of work than a heavier load with a less velocity, or a lighter load with a greater velocity.

## 276. Velocity Ratio.

The *velocity ratio* in any machine is the proportion between the movement of the power and the movement of the resistance, in the same interval of time; for example, in a punching press it may be 100 to 1 $= \frac{100}{1}$, and in a hydraulic crane 1 to 8 $= \frac{1}{8}$. These proportions also express the amount of the resistance (including friction), compared with the power or pressure applied. See also the definitions of *virtual velocity*, art. 278.

The term *purchase* of a machine is applied either to the motion or pressure of the resistance compared with the power; in above examples, the purchase of the punching press would be 100, that of the hydraulic crane 8, but the term is generally restricted to the gaining of pressure by the sacrifice of speed, as in the first case.

By the *mechanical advantage* of any machine is meant the ratio of the weight (or resistance) to the power, when in equilibrium. Sometimes improperly called the mechanical efficiency.

## 277. Principle of Virtual Velocities.

If any machine without friction be in equilibrium and the whole be put in motion, the initial pressure P will be to the final pressure $p$ as the final velocity V is to the initial velocity $v$, or $P : p :: V : v$, or $p\,V = P\,v$.

Instead of velocity (V and $v$) we may take "space moved over" (S and $s$).

In practice, as all machines have friction, $p$ will depend upon the friction, but V will be in accordance with the calculation of the leverage or gearing.

Let $e =$ the final pressure by experiment, then $p - e$ $=$ friction, and the coefficient or modulus of machine $M = \frac{e}{p}$.

### 278. Definitions of the Principle of Virtual Velocities.

*Rankine's.*—The effort and resistance are to each other inversely as the velocities, along their lines of action, of the points where they are applied.

*Twisden's.*—If a system of pressures, in equilibrium, act on any machine which receives any small displacement, consistent with the connection of the parts of the machine, the algebraical sum of the virtual moments of the pressure will equal zero.

### 279. Work, in Terms of Angular Motion.

$r$ = radius = leverage.
$2\pi r$ = circumference.
$p$ = pressure at circumference.
$rp$ = moment of pressure.
$n$ = number of revolutions.
$2\pi n$ = angular motion.
$rp \times 2\pi n$ = foot-lbs. work performed.
rate of work = work performed in a unit of time as 1 second or 1 min. —*Rankine.*

### 280. Angular Velocity.

The angular velocity of a wheel is the speed of a point in the circumference of an imaginary wheel with unity as radius, and making the same number of revolutions per minute as the given wheel.

Velocity is taken in feet per second.
Revolutions are taken at per minute.

$$\text{Circumferential velocity} = \frac{2\pi r n}{60} = \frac{\pi r n}{30} = \cdot 10472\, r\, n.$$

$$\text{Angular velocity} = \frac{2\pi (r) n}{60} = \frac{\pi n}{30} = \cdot 10472\, n.$$

$$\frac{\text{Velocity of any point in wheel}}{\text{radius of ditto in feet}} = \text{angular velocity}.$$

### 281. Angular Measurement of Forces.

A *radian*, or unit of angular rotation, is an arc of a length equal to radius; it contains 57·2958 degrees $= \frac{180^\circ}{\pi}$. A right angle therefore contains 1·5708 radians, two right angles 3·1416 radians, and four right angles 6·2832 radians; or one revolution $= 2\,\pi$ radians, and

$$n \text{ revolutions per minute} = \frac{2\,\pi\,n}{60} \text{ radians per second.}$$

$$\frac{\text{Degrees in an angle}}{57\cdot2958} = \text{No. of radians.}$$

$$\text{Radius} \times \text{No. of radians} = \text{length of arc.}$$

The angular velocity of a wheel may be measured in radians per second.

A *round* is the angular space traversed in one revolution. A round contains 6·2832 radians. The linear velocity of a point in a wheel is equal to the angular velocity × the distance in feet of the point from the axis. All points in a revolving wheel have the same angular velocity.

A *torque* (Jas. Thomson) is a system of forces, not meeting in one point, which, acting upon a body, may be parallel to and proportional to the sides of a closed polygon, but whose turning moments do not balance about any axis. It is equivalent to a "couple." In machinery it means turning moment or turning force × distance from centre of shaft.

In Ayrton and Perry's dynamometer coupling, or transmission dynamometer, the total amount of the forces of the springs in pound-feet, or the "torque," × angular velocity per minute ÷ 33,000 = the horse-power, thus:

$$\text{H.P.} = \frac{\text{torque} \times \text{angular } v. \text{ per minute}}{33{,}000}.$$

## 282. Angle of Twist.

A straight line drawn along a shaft not transmitting power, becomes a spiral while power is being transmitted. The angle between the spiral line at any point and the original direction divided by the radius of the shaft is called the angle of twist. —*Perry.*

## 283. Workshop Tools

are divided into two classes, hand tools and machine tools. In the former are included hammers, chisels, files, ratchet braces, spanners, &c.; and in the latter, lathes, planing, shaping, drilling and slotting machines, &c., in the fitting shop; and punching and shearing machines, bending rolls, steam hammers, &c., in the smiths' shop.

The machine tools are now mostly driven by steam power through shafting connected by belts.

A workshop should be so arranged that the raw material coming in at one end would be received at the various tools in the order of the work to be done upon it, and be removed in a finished state at the other end.

## 284. Hammers.

| Name. | Weight. | Length of Shaft. |
|---|---|---|
| | lbs. | inches |
| Sledge . . . . | 28, 24, 18 and 14 | 40 |
| Flogging . . . | 7 and 5 | 30 |
| Riveting , . . | 4 and 3 | 24 |
| Hand . . . . | 2 | 20 |
| Fitting . . . . | $1\frac{3}{4}$ | 16 |
| Bench . . . . | $1\frac{1}{2}$ | 14 |
| " . . . . | 1 | 12 |

## 285. Work of Hammer.

Hammer 2 lbs., velocity 20 feet per second, drives nail $\frac{1}{2}$ inch into hard wood; required the equivalent dead pressure. ($v$. after striking = 20 to 0, mean = 10; therefore $t$ in driving $\frac{1}{2}$ inch = $\frac{1}{240}$ of a second.) See art. 64.

$$1\text{st by } F = \frac{W\,v}{g\,t},\ \frac{2}{32\cdot2} \times \frac{20}{\frac{1}{240}} = 298 \text{ lbs.}$$

$$2\text{nd by } \frac{W\,v^2}{2\,g},\ \frac{2}{32\cdot2} \times \frac{20^2}{2} = 12\cdot42 \text{ ft.-lbs., and } \frac{12\cdot42}{\frac{1}{24}}$$

$$= 298 \text{ lbs. as before;}$$

but this will only be the *mean* pressure. From experiments it appears that the maximum pressure required is about $1\frac{3}{4}$ times mean pressure, so that the actual dead pressure required to force same nail same depth would be $298 \times 1\cdot75 = 521\cdot5$ lbs., and the force required to extract it, being about $\frac{4}{5}$ of pressure to insert it, would be $521\cdot5 \times \frac{4}{5} = 417$ lbs. Where the resistance varies simply as the depth driven, the maximum pressure is double the mean. The same principles apply to pile driving. See papers by the author on 'The Force of Hammers; or, Percussion *v.* Pressure,' and 'Timber Piling in Foundations and other Works.'

## 286. Impact of Moving Bodies.

In these formulæ mass may be substituted for weight without affecting the result.

| | | | | |
|---|---|---|---|---|
| $W$ = weight | of body | A | giving blow. | |
| $V$ = velocity | ,, | A | ,, | |
| $V^1$ = ,, | ,, | A | ,, | after impact. |
| $w$ = weight | ,, | B | receiving blow. | |
| $v$ = velocity | ,, | B | ,, | |
| $v^1$ = ,, | ,, | B | ,, | ,, |

| BODIES PERFECTLY SOFT OR INELASTIC. | BODIES PERFECTLY ELASTIC. |
|---|---|
| (1) Both moving in same direction. | |
| $V^1 = v^1 = \dfrac{W\,V + w\,v}{W + w}.$ | $V^1 = 2\,\dfrac{W\,V + w\,v}{W + w} - V.$ <br> $v^1 = 2\,\dfrac{W\,V + w\,v}{W + w} - v.$ |
| (2) A moving, B at rest. | |
| $V^1 = v^1 = \dfrac{W\,V}{W + w}.$ | $V^1 = 2\,\dfrac{W\,V}{W + w} - V.$ <br> $v^1 = 2\,\dfrac{W\,V}{W + w}.$ |
| (3) Both moving in opposite directions. | |
| $V^1 = v^1 = \dfrac{W\,V - w\,v}{W + w}.$ | $V^1 = 2\,\dfrac{W\,V - w\,v}{W + w} - V.$ <br> $v^1 = 2\,\dfrac{W\,V - w\,v}{W + w} - v.$ |

Resulting motion towards A if result $-$.
" " B " $+$.

Or, putting R = mutual action between two bodies moving in opposite directions,

$$R = \frac{W\,w\,(V + v)}{W + w}.$$

| | |
|---|---|
| $V^1 = \dfrac{w\,v - R}{w}.$ | $V^1 = \dfrac{w\,v - 2\,R}{w}.$ |
| $v^1 = \dfrac{W\,V - R}{W}.$ | $v^1 = \dfrac{W\,V - 2\,R}{W}.$ |

For intermediate condition of matter, between perfectly soft and perfectly elastic, use coefficient $e\,R$.

*Example of Case* 2.

Body A weighing W = 10 lbs., moving at velocity V = 20 feet per second, strikes body B weighing $w$ = 30 lbs. at rest. When perfectly soft or inelastic $\frac{W\,V}{W + w} = \frac{10 \times 20}{10 + 30}$ = 5 feet per second as the resulting velocity of A and B moving together. But, by formula for kinetic energy, if the units of work existing in A remain in the combined masses after striking, $\frac{W\,V^2}{2\,g} = \frac{(W + w)\,V_1^2}{2\,g}$, the resulting velocity would appear to be

$$V_1 = V\sqrt{\frac{W}{W + w}} = 20\sqrt{\frac{10}{10 + 30}} = 10 \text{ feet per second.}$$

The explanation is that the total *momentum* is always the same, but the *energy* is only constant when the bodies are perfectly elastic, i.e. when the restitution is complete. When the elasticity is imperfect, part of the *work* is used in compressing the particles, and the lost velocity is transformed into *heat*.

If the same bodies were perfectly elastic the resulting velocity of A would be

$$V^1 = 2\,\frac{W\,V}{W + w} - V = 2\left(\frac{10 \times 20}{10 + 30}\right) - 20 = -\,10 \text{ ft. per sec.,}$$

i.e. it would rebound at half the striking velocity, and the resulting velocity of B would be

$$v^1 = 2\,\frac{W\,V}{W + w} = 2\left(\frac{10 \times 20}{10 + 30}\right) = 10 \text{ feet per second in forward}$$

direction.

The energy before and after would be

$$\frac{W\,V^2}{2\,g} = \frac{W\,V_1^2}{2\,g} + \frac{w\,v_1^2}{2\,g},$$

$10 \times 20^2 = (10 \times -\,10^2) + (30 \times 10^2)$, or $4000 = 1000 + 3000$. Q.E.D.

### 287. Notes on Workshop Tools and Fittings.

Top of vice jaws from floor = 40 inches to 44 inches, say average of 42 inches, or level with the elbow.

### 288. Holtzapffel's Classification of Cutting Tools.

*Shearing* tools act by dividing the material operated on into two parts, which separate from each other by sliding at the surface of separation.

*Paring* tools cut a thin layer or strip called a shaving from the surface of the work, and thus produce a new surface.

*Scraping* tools scrape away small particles from the surface of the work, thus correcting the small irregularities which may have been left by the paring tool.

### 289. Angles of Tools.

| | Angle of Tool. |
|---|---|
| For wood . . . . . | 30° to 40° |
| „ wrought iron . . . | 60° |
| „ cast iron . . . . | 70° |
| „ brass . . . . . | 80° |

Angle of relief for all tools, 3° to 10°

### 290. Cutting Speed of Machine Tools.

| | Ft. per Min. | | | |
|---|---|---|---|---|
| Cast steel . . | 10 | to | 12 | |
| Mild . . . | 12 | „ | 15 | |
| Cast iron . . . | 15 | „ | 20 | |
| Wrought iron . . | 15 | „ | 25 | |
| Gun metal . . | 20 | „ | 40 | |
| Yellow brass . . | 40 | „ | 60 | |
| Wood . . . | 500 | „ | 2000 | when material revolves. |
| „ . . . | 3000 | „ | 5000 | when tool revolves. |
| Grindstone . . | 800 | „ | | |
| Milling wrought iron | 80 | „ | 100 | |
| „ cast steel . | 25 | „ | 30 | |

Average for wrought or cast iron in lathe, shaping, slotting, &c., 20 feet per minute.

Generally the cutting speed should be as fast as possible without the tool overheating and losing its temper.

### 291. Average Cutting Speeds and Feeds.

| Material. | Roughing. | | Finishing. | |
|---|---|---|---|---|
| | Speed. | Feed. | Speed. | Feed. |
| | ft. per min. | cuts per in. | ft. per min. | cuts per in. |
| Wrought iron . . . | 25 | 20 | 25 | 25 |
| Steel . . . . . | 18 | 25 | 15 | 30 |
| Cast iron . . . | 25 | 16 | 25 | 6 |

### 292. Speed of Machine Tools.

Speed of cut { Wrought iron, 20 feet per minute.
Cast „ 16 „ „
Cuts per inch, 16 to 80.

For flat work:

Speed in inches per second × 5 = speed in feet per minute.

For small diameters:

Diameter in inches × revolutions in 16 seconds = speed in feet per minute.

For large diameters:

$$\frac{\text{Diam. in inches} \times 16}{\text{Seconds for 1 revolution}} = \text{speed in feet per min.}$$

$$\frac{\text{Cutting speed in feet per min.} \times 5}{\text{Cuts per inch}} = \text{sq. ft. tooled per hour.}$$

—'*Engineering.*'

### 293. Cutting Speeds.

| | | |
|---|---|---|
| Shearing and punching . . | 2 | feet per minute. |
| Turning malleable cast iron . | 3 | „ „ |
| Screwing . . . . . . | 6 | „ „ |
| Turning steel . . . . | 10 | „ „ |
| „ cast iron . . . | 16 | „ „ |
| „ wrought iron . . | 21 | „ „ |
| „ bronze . . . | 30 | „ „ |

—'*English Mechanic.*'

### 294. Speed in Cutting Metals.

| | | |
|---|---|---|
| Turning chilled rolls . . . . | 3 to 4 | ft. per min. |
| Screw-cutting steel in lathe . . | 7½ | „ |
| Turning and planing steel . . | 10 | „ |
| Boring cast-iron cylinders . . | 12 | „ |
| Turning, planing and shaping cast iron . . . . . . . . | 15 to 20 | „ |
| Do. do. wrought iron and very soft cast iron . . . . . . | 20 „ 40 | „ |
| Do. do. steel . . . . . . | 24 „ 30 | „ |
| Do. do. brass . . . . . . | 36 „ 100 | „ |
| Screw-cutting gun-metal . . . . | 30 | „ |
| Turning copper . . . . . | 30 | „ |
| Band-saws for hot iron and steel . | 200 „ 300 | „ |
| Circular saws for do. do. . | 12,000 to 27,600 | „ |

—*Keerayeff.*

Circular saw, consisting of soft iron disc running at circumferential speed of 12,000 feet per minute, is used for cutting ends of steel rails, with jet of water playing on circumference of saw.

## 295. Speed of Milling Cutters.

| | Ft. per min. | | In. per min. |
|---|---|---|---|
| For brass . . . | 120 | Feed . . . | 2·66 |
| „ cast iron . . . | 60 | „ . . . | 1·66 |
| „ wrought iron . | 48 | „ . . . | 1·00 |
| „ steel . . . | 36 | „ . . . | 0·50 |

Angle of teeth 70°, clearance angle 10°.
4 inches diameter = 35 teeth, 6 inches diameter = 43 teeth, 8 inches diameter = 51 teeth.

—*Addy.*

## 296. Resistances in Machine Tools.

### TWIST DRILL.

Pressure on head of twist drill in lbs. requisite to produce proper cut = diameter of drill in inches and decimals × 1500.

### LATHE.

| Material. | Width of Cut. | Depth of Cut. | Speed of Cut. | Resistance to Traverse of Tool. |
|---|---|---|---|---|
| | inches | inches | ft. per min. | lbs. |
| Steel . . . . | $\frac{1}{20}$ | $\frac{1}{20}$ | 5 | 600 |
| Wrought iron . . . | $\frac{1}{20}$ | $\frac{1}{10}$ | 10 | 700 |
| Cast iron . . . | $\frac{1}{20}$ | $\frac{1}{16}$ | 15 | 325 |

### PLANING MACHINE.

Cast iron, width of cut $\frac{1}{16}$ inch, speed of cut 11 feet per minute. With depth of cut = $\frac{1}{32}$ inch pressure against tool varied from 356 to 396 lbs., averaging 373 lbs., or 4065 ft.-lbs. work per minute. With depth = $\frac{1}{16}$ inch, pressure varied from 340 to 559 lbs., averaging 458 lbs., or 5000 foot-lbs. work per minute.

MILLING CUTTERS MADE FROM "BÖHLER" STEEL.

| | |
|---|---|
| Diameter of cutter . . . . . | 36 mm. |
| Revolutions per minute . . . . | 110 |
| Travel per minute . . . . . | 32 mm. |
| Feed . . . . . . . . | 5 „ |
| Length of cut . . . . . . | 80 „ |
| Weight of steel cut per hour . . | 6 kilos. |

The above results have been obtained by work on pieces of middling hard steel, that is to say, a steel equal to a resistance of 55 to 60 kilos. per mm.; the average time occupied has been 5 hours, without showing any deterioration to the tool.

### 297. POWER REQUIRED TO DRIVE LATHE.

$HP_L$ = Horse-power absorbed running light.
$HP_W$ = „ „ in work.
$HP$ = Total „ „ $= HP_L + HP_W$.
$N$ = number of revolutions per minute.
$C$ = constant depending on material and class of tool, average 0·026 cast iron, 0·030 wrought iron, 0·044 steel.
$W$ = weight of chips removed per hour in lbs. $= 18 \cdot 7\, S\, d f$.
$S$ = cutting speed in feet per minute.
$d$ = depth of cut in inches.
$f$ = feed per revolution in inches.

Small Lathe (under 20-inch swing).

Back gear thrown out $HP_L = 0 \cdot 095 + 0 \cdot 0012\, N$.
„ „ in „ $= 0 \cdot 10 + 0 \cdot 006\, N$.
„ „ „ $HP_W = C\, W$.

—*Flathers.*

Under ordinary conditions the same horse-power would remove 6 lbs. of cast iron, 5 lbs. of wrought iron, and 3½ lbs. of steel chips per hour. —'*Mechanical World.*'

## 298. Screw Cutting.

Set of change wheels numbers 22; increasing by 5 teeth from 20 to 120, two being alike, generally 80 or 90. When 25 in a set, the extra wheels are 130, 140 and 150.

Wheels of 10 and 15 teeth are supplied when the screw-cutting gear works the slide rest.

Leading screw has usually 2, 3 or 4 threads per inch.

Double train must always be used when $\dfrac{\text{leading screw}}{\text{screw required}}$ is less than $\frac{1}{6}$, generally when less than $\frac{1}{4}$.

When the number of threads per inch required to be cut can be divided without remainder by the number of threads per inch in the leading screw, the clamping nut under the saddle will drop into gear with the leading screw without chalking.

Always retain the mandrel wheel for a screw-cutting train when possible.

### TO FIND THE WHEELS FOR ANY PITCH.

Single train—

$$\frac{\text{Threads per inch in leading screw}}{\text{,, \quad ,, \quad screw to be cut}} = \frac{\text{driver}}{\text{follower}}.$$

Double train—

$$\frac{\text{Threads leading screw}}{\text{Threads screw required}} = \frac{\text{driver}}{\text{follower}} \times \frac{\text{driver}}{\text{follower}}.$$

### EXAMPLES OF CHANGE WHEELS.

Single trains—

Leading screw, 4 threads
Required ,, 7 ,, $\quad \frac{4}{7} \times \frac{5}{5} = \frac{20}{35}$, or $\times \frac{15}{15} = \frac{60}{105}$

Leading ,, 4 ,,
Required ,, $2\frac{3}{4}$ ,, $\quad \frac{4}{2\frac{3}{4}} = \frac{16}{11} \times \frac{10}{10} = \frac{160}{110} \div \frac{2}{2} = \frac{80}{55}$

Leading ,, 4 ,,
Required ,, ·75 ,, $\quad \frac{\cdot75 \times 100 \times 4}{100} = \frac{300}{100} = \frac{30}{10} \times \frac{4}{4} = \frac{120}{40}$

Double trains—

| | |
|---|---|
| Leading screw, 4 threads<br>Required „ $\frac{5}{8}$ pitch | $\frac{5 \times 4}{8} = \frac{5 \times 4}{2 \times 4} = \frac{50 \times 40}{20 \times 40} = \mathbf{\frac{50 \times 80}{20 \times 80}}$ |
| Leading „ 4 threads<br>Required „ 100 „ | $\frac{4}{100} = \frac{2 \times 2}{5 \times 20} = \frac{20 \times 20}{50 \times 200} = \mathbf{\frac{20 \times 10}{50 \times 100}}$ |
| Leading „ 4 „<br>Required „ ·08 „ | $\frac{4 \times \cdot 08 \times 100}{100} = \frac{4 \times 8}{10 \times 10} = \frac{40 \times 80}{100 \times 100} = \mathbf{\frac{20 \times 80}{50 \times 100}}$ |

Trains to be used are shown in broad-faced type.

### 299. Screw for Worm Wheel.

To find change wheels to cut screw,

$D$ = Diametral pitch of worm wheel.
$d$ = diameter of worm wheel at pitch circle.
$n$ = number of threads per inch in leading screw.
$t$ = number of teeth in wheel.

$$\frac{\pi n}{D} = \frac{22\, n}{7\, D} = \frac{Driver}{Follower},$$

$$\frac{\pi d n}{t} = \frac{22\, d n}{7\, t} = \frac{Driver}{Follower}.$$

To cut double, treble, or more threads or worms:—

Find the smallest set of wheels that will cut the required pitch single thread, then multiply the drivers by the number of threads required.

### 300. Velocity of Wood-working Machinery.

| | | |
|---|---|---|
| Saw frame (several saws) . . . | 8 | feet per second. |
| „ (one saw) . . | 10 to 15 | „ „ |
| Band saw . . . . . | 40 to 50 | „ „ |
| Turning wood . . . . | 15 to 40 | „ „ |
| Revolving cutters . . . | 60 to 100 | „ „ |
| Circular saw (across grain) . | 80 to 100 | „ „ |
| „ (with grain) . | 100 to 130 | „ „ |

—*Keerayeff.*

To saw green oak lengthways requires 29,000 foot-lbs. work per foot super.

### 301. Speed of Polishing and Grinding.

| | | | |
|---|---|---|---|
| Tool grindstone . . . . | 400 to 900 | feet | per minute. |
| Polishing by emery and oil . | 750 | „ | „ |
| „ by grindstone . . | 2000 | „ | „ |
| „ by dry emery wheel | 3000 to 4000 | „ | „ |

—*Keerayeff.*

### 302. Rolling Mill Speeds.

Velocity of rolls in feet per second.

| | |
|---|---|
| Squeezing . . . . . | 3 |
| Plates . . . . . . | 4 to $6\frac{1}{2}$ |
| Rails, angles and tees . . . | $5\frac{1}{2}$ |
| Rods and bars . . . . | 6 to 8 |
| Fly-wheels for mill . . . | 80 to 100 |
| Wire-drawing rollers . . . | 1 to $3\frac{1}{4}$ |
| Cold rolling . . . . | $\frac{1}{3}$ |
| Plate bending . . . . | $\frac{1}{16}$ |

—*Keerayeff.*

### 303. Shearing and Punching.

Resistance to shearing of wrought iron averages 50,000 lbs. per square inch area of surface cut. This will be the pressure required on the material at the commencement of the stroke.

The mechanical work in punching or shearing is estimated by Weisbach as this pressure exerted through one-sixth the thickness of the plate, and the coefficient or modulus of the machine as ·66, the friction being taken at 33 per cent. of the gross pressure.

For rectangular bars the pressure may be taken as exerted through one-fourth the thickness, and for round bars one-third the diameter.

Formula for calculating power required:

$t$ = Thickness of plate or bar.
$l$ = Length or circumference of cut.
$f$ = Resistance of material to shearing.
M = Modulus of machine, say ·66.
P = Gross pressure in lbs.

$$P = \frac{t\,l\,f}{M}.$$

Pressure required to punch wrought-iron plates (from experiments).

| | $d$ | | $t$ | | P | | $c$ |
|---|---|---|---|---|---|---|---|
| To punch | $\frac{1}{8}$ | hole in | $\frac{1}{8}$ | plate requires | $2\frac{1}{4}$ | tons = | 144 |
| ,, | $\frac{1}{4}$ | ,, | $\frac{1}{4}$ | ,, | $6\frac{1}{2}$ | ,, | 104 |
| ,, | $\frac{3}{8}$ | ,, | $\frac{3}{8}$ | ,, | 13 | ,, | 92 |
| ,, | $\frac{1}{2}$ | ,, | $\frac{1}{2}$ | ,, | 22 | ,, | 88 |
| ,, | $\frac{5}{8}$ | ,, | $\frac{5}{8}$ | ,, | $33\frac{1}{2}$ | ,, | 86 |
| ,, | $\frac{3}{4}$ | ,, | $\frac{3}{4}$ | ,, | $47\frac{1}{4}$ | ,, | 84 |
| ,, | $\frac{7}{8}$ | ,, | $\frac{7}{8}$ | ,, | $62\frac{3}{4}$ | ,, | 82 |
| ,, | 1 | ,, | 1 | ,, | 80 | ,, | 80 |

$$P = d \times t \times c.$$

Approximately diameter × thickness × 88 = pressure in tons; or, area of cut surface × 28 = pressure in tons.

Diameter of die = diameter of punch × $1\frac{1}{16}$.

Point of punch coned 5° with hollow curve.

Shearing: falling blade bevelled 3° to 8° in elevation, and 15° in section; fixed blade horizontal and square.

## 304. Steam Hammers.

Weight of hammer in lbs. for shaft forging = 80 × diameter shaft inches².

Weight of anvil = 10 times weight of hammer.

### 305. Steel Forging Presses.

Pressure required = 16,000 lbs. per square inch on the die.

### 306. Observed H.P. required to Drive Shop Tools.

| | |
|---|---|
| Small screw-cutting lathe, 12-inch swing | 0·33 |
| Screw-cutting lathe, 20-inch swing | 0·47 |
| Large facing lathe, 68-inch swing | 0·91 |
| Small shaper, 9½-inch stroke | 0·24 |
| Shaper, 15-inch stroke | 0·63 |
| Large shaper, 29-inch stroke | 1·14 |
| Planer, 36 inches × 36 inches × 11 feet | 0·84 |
| Large planer, 76 inches × 76 inches × 57 feet | 1·47 |
| Small drill press | 0·62 |
| Large drill press | 1·24 |
| Radial drill, 6-foot swing | 0·53 |
| Small slotter, 8-inch stroke | 0·28 |
| Medium slotter, 9½-inch stroke | 0·44 |
| Large slotter, 15-inch stroke | 0·95 |
| Universal milling machine | 0·28 |
| Milling machine, 13-inch cutter head, 12 cutters | 0·66 |
| Small punch and shear combined, 7½ inches × 1½ inches | 0·79 |
| Large plate shears, knives 28 inches × 3-inch stroke | 7·12 |
| Large punch press, 3-inch stroke through 1½ inches thick | 4·41 |
| Plate bending rolls, 9½ feet × 13 inches | 2·70 |
| Wood planer, 28-inch rotary knives | 5·00 |
| Circular saw for wood, 23 inches | 3·23 |
| Circular saw for wood, 35 inches | 5·64 |
| Band-saw for wood, 34-inch wheel | 0·96 |
| Tenon and mortising machine | 2·73 |

| | |
|---|---|
| Wood moulding machine, $7\frac{1}{2}$ inches × $2\frac{1}{2}$ inches . . . . . . . . | 2·45 |
| Grindstone for tools, 31 inches × 6 inches, 680 feet per minute . . . . . | 1·55 |
| Grindstone for stock, 42 inches × 12 inches, 1680 feet per minute . . . . . | 3·11 |
| Emery wheel saw-grinder, $11\frac{1}{2}$ inches × $\frac{1}{4}$ inch . . . . . . . | 0·56 |

—*Flathers.*

# SECTION VII.

# POWER TRANSMISSION BY BELTS, ROPES, CHAINS AND GEARING.

### 307. Transmission of Motion.

By *rolling contact*, as spur wheels and pinions, crown wheel and pinion, face wheel and lantern, bevel wheels, cones, rack and pinion, &c.

By *sliding contact*, as inclined plane, wedge, cams, swash plate, crown wheel escapement, screw, &c.

By *wrapping contact*, as cords and pulleys, belts and pulleys or riggers, speed pulleys, capstan, fusee of watch, &c.

By *link work*, as levers, cranks, treadle of lathe, &c.

—*Tomkins' 'Machine Construction.'*

### 308. Notes on Belt Gearing.

Coefficient of friction between ordinary leather belting and cast-iron pulleys or drums = ·423. Ultimate strength of ordinary leather belting = 3086 lbs. per square inch. Belts vary from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch thick, average $\frac{7}{32}$ inch. The strongest part is one-third of the thickness on the flesh side.

| | Breaking Strain. | Safe Working Strain. |
|---|---|---|
| Through solid part . | 675 lbs. . | 225 lbs. per inch wide. |
| Through riveting . | 382 lbs. . | 127 " " |
| Through lacing . . | 210 lbs. . | 70 " " |

The working strength of the belt must be taken as that of its weakest part, which is the lacing.

The tension of the driving side, which must not exceed the safe working strength of the belt = force transmitted + mean normal tension.

The force transmitted = the difference between the tension of the driving side and the tension of the following side. —*Welch's 'Designing Belt Gearing.'*

When the arc of contact = 180°, the force able to be transmitted may be taken as 50 lbs. per inch wide. If more or less than half circumference be embraced by belt, the force transmitted may be increased or reduced by about 2·8 lbs. for every 10° difference from 180°.

The sum of the tensions, or cross strain on shafting, may be taken as 90 lbs. per inch wide.

The lower side of a belt should be made the driving side when possible, so that the arc of contact may be increased by the sagging of the following side.

To increase the capability for transmission of power, the diameters of the pulleys may be increased, retaining the same ratio, the increase of power being obtained by the increased velocity alone.

Wide belts are less effective per unit of sectional area than narrow belts. Where a belt would exceed 18 inches wide it is better to use two belts. Long belts are more effective than short belts. All belts should hang slack when not in use.

The velocity of lathe belts should be from 25 to 50 feet per second = 1500 to 3000 feet per minute.

Convexity of pulleys to receive belt = $\frac{1}{2}$ inch per foot wide, turned with a broad tool and coarse feed to give a non-slipping surface. Width of pulley = $\frac{1}{4}$ more than belt.

The proportion between the diameters of two pulleys working together should not exceed 6 to 1.

Ordinary shop shafting 100 revolutions per minute: belting say 1000 to 1500 feet per minute.

The revolutions per minute of two pulleys embraced by the same belt will be inversely proportional to their diameters.

Pulleys from 2 to 3 feet diameter transmit approximately 1 H.P. per inch width of belt at ordinary velocities; or square inches belt in contact with pulley $\times$ velocity feet per minute $\div$ 72,000 = H.P.

### 309. Strength of Leather Belts.

H.P. = Effective H.P. transmitted.
$v$ = velocity of belt in feet per minute.
$w$ = width in inches of single belt.

$$\text{H.P.} = \frac{w\,v}{470}. \qquad w = \frac{470\,\text{H.P.}}{v}.$$

For double belts multiply H.P. $\times$ 1·5 or $w \times \frac{2}{3}$.

—*Bagshaw & Sons, Batley.*

Another rule:—

R = revolutions per minute.
D = diameter pulley feet.
$c$ = 25 for single belts.
17 for double belts.
$d$ = diameter shaft inches, but if overhung, increase by $\frac{1}{4}\,d$.

$$\text{H.P.} = \frac{3\,w\,\text{D}\,\text{R}}{25\,c}. \qquad d = \sqrt[3]{\text{H.P.}}$$

Another rule (A. Towler):—

$d$ = diameter smaller pulley inches.
$a$ = ratio of arc covered by belt to circumference.

$$\text{Single belts H.P.} = \frac{d\,w\,a\,\text{R}}{2000}.$$

$$\text{Double ,, H.P.} = \text{do.} \times 1{\cdot}75.$$

### 310. Large Double Belts.

$w$ = width of double belt in inches.
$v$ = velocity feet per second.

$l$ = length inches of arc of contact on lesser pulley.
H.P. = horse-power transmitted.

$$w = \frac{66000 \times \text{H.P.}}{l \times v}.$$ —*Evan Leigh.*

Double belts should not be used over pulleys less than 3 feet 6 inches diameter.

Leather link belting is the most suitable for transmitting great power and running at a high velocity.

311. To Find Length of Belt Embracing Pulleys.

R = radius of larger pulley to centre of belt.
$r$ = „ smaller „ „
E = „ equal pulleys.
$d$ = distance between centres of pulleys.
$n$ = number of degrees between radii from tangent points.
$t$ = length of each of the tangent portions.
C = length of part embracing circumference of larger pulley.
$c$ = length of part embracing circumference of smaller pulley.
L = total length exclusive of laps.

$$t = \sqrt{d^2 - (\text{R} - r)^2}.$$

$n$ = tabular degrees corresponding to cosine having value of $\frac{\text{R} - r}{d}$.

$$\text{C} = \frac{360 - 2n}{360} \times 2\pi\text{R}.$$

$$c = \frac{2n}{360} \times 2\pi r.$$

$$\text{L} = 2t + \text{C} + c.$$

$$\text{E} = \frac{\text{L} - 2d}{2\pi}.$$

### 312. Notes on Hemp Ropes.

Italian hemp ropes are stronger than Russian hemp.

New white ropes are stronger and more pliable than tarred ropes, but the latter retain their strength for a longer period, owing to the protection afforded against atmospheric influences. The quantity of tar found most suitable is about 15 per cent. of the weight of the rope.

Tarred ropes are stiffer than white by about one-sixth, and in cold weather somewhat more.

Ropes which have been some time in use are more flexible than new ones; the stiffness of ropes increases after a little rest.

Wet ropes, if small, are a little more flexible than dry; if large, a little less flexible. Ropes shorten and swell when wetted. A wet rope, or one saturated with grease, loses half its strength.

There is considerable loss of strength from strain, and exposure after use, although a rope may appear perfectly sound.

A "plain-laid" rope consists of three twisted strands twisted together. A "hawser-laid" rope is made by twisting three plain-laid ropes together, so that a section would show nine strands.

Ropes are usually measured by their circumference: hence a 6-inch rope is one 6 inches in circumference, or about $1\frac{7}{8}$ inch diameter.

All ropes should be kept dry and free from lime.

Round ropes are better than flat for all purposes.

Ultimate strength of new white ropes is about 6000 lbs. per square inch sectional area, but good ropes may stand 10,000 lbs. per square inch.

Small ropes are slightly stronger, in proportion to their sectional area, than large ones.

Double rope slings are not twice the strength of single rope, owing to inequality of strain; but in a rope fall with sheaves in good order, each fold of the rope may be counted for the strength.

The work absorbed in bending a rope fall over a sheave varies with the quality of the rope, directly as the tension, as the diameter², and inversely as diameter of sheave, and is irrespective of velocity.

Include weight of running block in calculating load on fall, and both blocks together with the rope, in weight on strop. Snatch block makes practically no difference in lifting power, if it has a good lead.

In rope tackle it is usual to allow for the friction in bending round sheaves, &c. = $\frac{1}{3}$ of the load to be lifted.

### 313. Strength of Manila Ropes.

Manila rope varies from 10,000 lbs. per sq. inch net section ultimate strength for a 2-inch diameter rope to 12,000 lbs. per sq. inch for a $\frac{1}{2}$-inch diameter rope.

Net sectional area = 0·81 of area of circumscribing circle.

$d$ = diameter inches circumscribing circle.

S = breaking weight in lbs.

$$S = 100\, d^2\, (83 - 10\, d).$$

—*Prof. J. J. Flather.*

### 314. Formulæ for Strength of Hemp Ropes.

| | | | |
|---|---|---|---|
| Breaking weight new rope, cwts. | | | = circumference² × 5. |
| Safe load on | ,, | ,, | = wt. lbs. per fath. × 3. |
| B.W. new stretched rope | | ,, | = (diameter in $\frac{1}{8}$ths)². |
| Safe load | ,, | ,, | = wt. lbs. per fath. × 4. |
| ,, on new rope fall | | ,, | = circumference². |
| ,, good | ,, | ,, | = $\frac{2}{3}$ ,, |
| ,, sound old | ,, | ,, | = $\frac{1}{2}$ ,, |
| Weight of clean dry rope per fathom, in lbs. . . . | | | = $\frac{1}{4}$ ,, |
| Minimum diameter of sheave in inches . . . . . | | | = circf. rope + 2 in. |

Flat ropes, width about 4 times thickness.

,, wt. lbs. per fath. approx. = circf. × 2.

,, B.W. tons = wt. lbs. per fathom.

### 315. Hide Ropes.

Made by G. Pitts & Sons, Kirkdale, Liverpool, for hand-power delivery cranes, at 1*s.* 10*d.* per lb.

Dipped in Stockholm tar to prevent destruction by rats.

$$\frac{\text{Circumference}^2}{5} = \text{weight lbs. per fathom.}$$

### 316. Fly Ropes.

When power is transmitted over considerable distances by an endless rope running at a high velocity, the rope is called a fly rope. Much used in engineering shops for driving travelling cranes, carrying heavy pieces of machinery. A three-ply manila rope, or cotton rope, with beeswax well rubbed in together with a little blacklead, is best. Run 3000 to 5000 feet per minute in cast-iron pulleys with V-grooves, angle 30° to 45°, latter for dry rope, former if lubricated. Working strain transmitted about 50 lbs. per circular inch area. Rope tightened by jockey pulley giving 250 to 300 lbs. per circular inch stress. Total stress must not exceed one-twentieth ultimate strength. Supported every 10 or 12 feet by flat plates of chilled cast iron. Friction of pulleys is inversely as their diameter, they should not be less than 30 times diameter of rope. By experiment, a new rope one-quarter inch diameter stretched 1 inch per foot per cwt.

Breaking weight in lbs. averages 720 × circumference², but ropes above 1 inch diameter are comparatively weaker, and below that size stronger. Mechanical efficiency of fly ropes = ·6.

### 317. Rope Driving.

$a$ = sectional area of rope in square inches.
$s$ = speed in feet per minute.
$n$ = number of ropes.
H.P. = effective horse-power transmitted.
$c$ = constant = hemp 100.

$$\text{H.P.} = \frac{c\,a\,n\,s}{33{,}000}; \qquad a = \frac{33{,}000\ \text{H.P.}}{c\,n\,s}.$$

—*J. Bagshaw & Sons, Batley.*

*Leather rope*, 8 narrow strips secured together and properly jointed, forming $1\frac{1}{2}$ inch square, running in V-groove, angle 90°, weighs 1 lb. per foot run and will transmit 320 lbs. per square inch of section.

*Cotton rope*, $1\frac{3}{4}$ inch circumference, weighing 1 lb. per foot run, will transmit 50 I.H.P. at velocity of 5000 feet per minute (600 lbs. less 60 for tension = 540 lbs. working strain).

*Steel rope*, $\frac{1}{2}$ inch diameter, weighing $\frac{1}{3}$ lb. per foot run, will bear working stress of 405 lbs.

*Hemp ropes*, although stronger than cotton, do not stand so well. Approximate H.P. of hemp rope = circumference in inches × diameter of driving pulley in feet × revolutions per minute ÷ 200. Another rule: H.P. = circumference$^2$ × velocity in feet per minute × one less than number of ropes ÷ 5000.

### 318. Curve of Rope.

A rope or chain when deflected by its own weight hangs in a catenary curve. It approximates to a parabola and is indistinguishable from one when the deflection is not more than one-tenth of the span.

### 319. Tests of Ropes.

| — | Ultimate Tension. | Elongation. |
|---|---|---|
| | tons per sq. in. | per cent. |
| White hemp | 4·75 | 18 |
| Tarred hemp | 3·5 | 16 |
| White manila | 4·5 | 15 |
| White aloes | 2·5 | .. |
| Esparto and cocoa fibre | 1·0 | .. |
| Flat ropes, hemp or manila tarred | 3·5 | 5 |

Round ropes, with moderate attention, may be worked at a stress equal to one-third breaking stress, and flat ropes at one-fourth.

### 320. Average Tensile Strength of Ropes.

Specimens 13 feet long, ends wound on grooved pulleys.

| | lbs. per sq. inch. |
|---|---|
| White hemp . . . | 10,500 to 11,200 |
| Tarred hemp . . . | 7,700 „ 8,400 |
| White manila . . . | 9,800 „ 10,600 |
| White aloes . . . | 5,600 „ 7,000 |
| Flat, tarred hemp, or manila | 7,800 „ 8,400 |
| Unannealed wire rope . (elongation 6 to 8 per cent.) | 55,000 |
| Annealed wire rope . . (elongation 12 to 15 per cent.) | 45,000 |

Factor of safety 3 to 4. —*A. Duboul.*

### 321. Wire Ropes for Lifts.

Diameter of pulley in inches = circumference of rope (Lang's lay) in sixteenths of an inch.

### 322. Experiments on Wire Rope at Forth Bridge.

Crucible cast steel wire rope was used. With a diameter of sheave = 6 times *circumference* of rope, rope bent over sheave 5000 times before failure commenced, 15,000 before final destruction.

With a diameter = 8 times circumference, 10,000 times and 36,000 respectively.

### 323. Lang's Patent Wire Ropes.

| | Bessemer Steel. | Crucible Steel. | Patent Steel. | Plough Steel. |
|---|---|---|---|---|
| Strength of material in tons per square inch . | 45 | 56 | 75 | 111 |
| Round rope, 6 strands of 6 wires each, up to . | 4 in. circf. | 3 in. | $3\frac{1}{2}$ in. | 4 in. |
| | 9 wires in each strand above these sizes. | | | |
| Approx. B.W. in tons . | $= c^2 \times 1 \cdot 5$ | 2 | $2 \cdot 5$ | $3 \cdot 5$ |
| Working load . . | $= \frac{1}{10}$ breaking weight. | | | |

Weight of round wire ropes in lbs. per fathom = circf.$^2 \times \frac{7}{8}$.

—*J. Bagshaw & Sons, Batley.*

## 324. R. S. Newall & Co.'s Iron Wire Ropes.

Round—

Weight in lbs. per fathom = $C^2 \times \frac{7}{8}$.

B.W. tons = weight in lbs. per fathom × 2.

Safe load cwts. = ,, ,, × 6.

Flat—

Width = $4\frac{1}{2}$ to $5\frac{1}{2}$ times thickness.

Sectional area × 10 = weight in lbs. per fathom.

Weight in lbs. per fath. × $\frac{9}{5}$ = B.W. tons.

B.W. tons × $\frac{20}{9}$ = safe working load cwts.

Drum for wire rope = 2 feet 6 inches diameter for every $\frac{1}{8}$ inch diameter of rope, speed 30 to 50 miles per hour. For slow speeds drum 80 times diameter of rope.

## 325. Strength of Chains.

| $d$ = Diameter of iron in $\frac{1}{8}$ths of an inch. | | | Example $\frac{3}{4}$ Chain. tons | cwts. |
|---|---|---|---|---|
| B.W. in tons, B.B. short-link crane chain . . | = | $\frac{1}{2}d^2$ | 18 | 0 |
| ,, ,, ordinary chain . . . . . . | = | $\frac{2}{5}d^2$ | 14 | 8 |
| ,, ,, ,, ,, (Anderson) . . | = | $\frac{3}{8}d^2$ | 13 | 10 |
| Elswick test in tons, 10 per cent. above Admiralty proof . . . . . . . . . | = | $\frac{33}{160}d^2$ | 7 | $8\frac{1}{2}$ |
| Admiralty proof strain in tons . . . . . | = | $\frac{3}{16}d^2$ | 6 | 15 |
| Safe load in tons (Molesworth, 11th ed.) . . | = | $\frac{1}{8}d^2$ | 4 | 10 |
| ,, ,, at 5 tons per square inch sectional area | = | .. | 4 | $8\frac{1}{2}$ |
| ,, ,, in tons (Molesworth, 21st ed.) . . | = | $\frac{1}{9}d^2$ | 4 | 0 |
| ,, ,, in tons, common rule . . . . . | = | $\frac{1}{10}d^2$ | 3 | 12 |
| Maximum temporary load on good annealed chain in cwts. . . . . . . . . | = | $2d^2$ | 3 | 12 |
| Safe load, ordinary chain (Anderson), in tons . | = | $\frac{3}{32}d^2$ | 3 | $7\frac{1}{2}$ |
| ,, ,, for ordinary cranes, in cwts. . . | = | $1\frac{1}{2}d^2$ | 2 | 14 |
| ,, ,, at 3 tons per sq. inch sectional area . | = | .. | 2 | 13 |
| ,, ,, coal cranes, in cwts. . . . . . | = | $1\frac{1}{4}d^2$ | 2 | 5 |
| ,, ,, old chain, quality and condition unknown, in cwts. . . . . | = | $d^2$ | 1 | 16 |
| Weight in lbs. per fathom, short link crane chain | = | $d^2$ | 36 | |
| ,, ,, ,, ordinary ,, | = | $\cdot 88d^2$ | $31\frac{1}{2}$ | |

Safe load (5 ton cranes and upwards) in tons = $\frac{1}{8}d^2$ when made of good iron, but large chains are frequently of common quality.

| | |
|---|---|
| Size of links for crane chains | $= 3\frac{1}{3}d \times 4\frac{2}{3}d$. |
| Admiralty proof strain on rings, in tons | $= d$ in $\frac{1}{8}$ths$^2 \div 16$. |
| ,, ,, stud chain ,, | $= d$ in $\frac{1}{8}$ths$^2 \times \cdot 281$. |
| Common chain cables, B.W. lbs. | $= 1{,}000{,}000\ (\frac{1}{4}d)^2$. |

## 326. Remarks on Crane Chains.*

$\frac{9}{16}$ inch B.B. tested short link crane chain (Crown S.C.) should break with a load of 13 tons, if the iron bar from which it is made break with 26 tons per square inch ultimate stress; but a test-piece of the chain 4 feet long breaks usually with a load of 9 to 10 tons, generally opening at the welds. Each chain is tested before use with a maximum load of $4\frac{1}{2}$ tons, examined link by link, and used on hydraulic coal cranes to lift maximum gross load of $1\frac{1}{4}$ tons, examined again at frequent intervals and annealed; any links reduced by wear to $\frac{1}{2}$ an inch at ends are condemned as worn out; worn links cut out and remainder used down to same limit. A good chain, properly looked after, will make from 100,000 to 150,000 lifts before it is entirely worn out. These chains occasionally fail in use, although the factor of safety adopted allows so great a margin.

## 327. Examination of Chains at the Docks in London.

All chains are taken down, annealed and examined as follows, viz. :—

Hydraulic crane, lead, lift, &c., chains, every six months.

Hand and steam crane, traveller, dockgate and chain gear, every twelve months.

The chain gear comprises chain runners, chain necklaces, sweeping and guy chains, chain slings, cattle slings, shackles, dogs and lead hooks.

* See paper on 'Use and Care of Chains for Lifting and Hauling,' read by the author before the Civil and Mechanical Engineers' Society, 1887.

### 328. Circular Rings for Mooring, and Sling Chains.

Circular rings in connection with mooring chains are made of a diameter proportionate to the size of chain, fixed by each maker, but generally four to six times the diameter of the iron. The Admiralty test for rings depends upon the diameter of the iron alone, and is independent of the diameter of the ring. It is

$$\text{Test load cwts.} = 1\tfrac{1}{4}\,(d \text{ in } \tfrac{1}{8}\text{ths})^2.$$

To find proper diameter of circular ring in mooring and sling chains:

$d$ = diameter of iron of chain in inches suitable for lifting given load.
D = diameter of iron of ring in inches.
R = mean radius of ring in inches.

$$D = \sqrt[3]{R\,d^2}.$$

### 329. Toothed Gearing.

A *spur wheel* has the teeth projecting radially on the circumference.

A *pinion* is the name given to the smaller of two wheels working in gear together. Hence spur wheel and spur pinion, bevel wheel and bevel pinion.

A *bevel wheel* has the teeth projecting on a rim which is inclined to the plane of the circumference at an angle usually between 30° and 60°.

*Mitre wheels* are bevel wheels of equal size, geared together at an angle of 90°.

A *crown wheel* has the teeth projecting at right angles to the plane of the circumference.

A *lantern wheel* has round pins to act as teeth, fixed between two discs, near the circumference.

A *hunting-cog* is an additional tooth on a wheel making the teeth of the wheel and pinion *prime* to each other and equalising the wear. *Prime numbers* are those which have no divisor in common.

A *mortice wheel*, or shell wheel, is a cast-iron wheel from ordinary patterns, but with hard wood teeth secured in mortices cast in the rim.

A *rag wheel* is a wheel with strong projections upon it which enter the spaces of a special chain called a *pitched chain*, or link chain, for transmitting power.

An *intermediate wheel*, or idle wheel, on a screw-cutting lathe is used to connect two wheels on different spindles without altering their velocity ratio.

A *Marlborough wheel* is one of double breadth, gearing at the same side into two wheels on different shafts, whose axes are so nearly in the same line as to prevent the use of ordinary spur gear. In effect it is the same as an intermediate wheel.

A *Geneva stop* consists of a disc provided with one tooth, and another disc with five or more spaces, all the parts between the spaces (except one) being hollowed to fit the first disc, so that at each revolution of the first disc the tooth carries the second one through a portion of a revolution, until further rotation is prevented by the part which is not hollowed out coming into contact with the shoulder at side of single tooth. It is a device to prevent overwinding.

A *fusee* is a conical drum upon which a chain is wound to equalise the effect of a coiled spring, by giving a varying leverage, as in a watch, clock, or other mechanism.

### 330. Notes on Toothed Gearing.

Pinions, wheels and racks are made of cast iron, cast steel, and malleable cast iron; the latter is strong, but liable to twist or warp. Pinions are sometimes made of wrought iron; small gearing is frequently made of gun-metal.

If moulded from patterns wheels should be geared so that the taper ends of teeth are on opposite sides. Gearing is increased in strength by shrouding or flanging up to pitch line.

The pitch line or pitch circle is the mean circumference of the teeth, or the circumference of a plain wheel without teeth, which would produce the same velocity-ratio if slipping were prevented. The teeth are only to prevent slipping.

The pitch of the teeth is the distance from a point on one tooth to a similar point on an adjacent tooth measured along the arc of the pitch circle.

The comparative wear of gearing is inversely proportional to the number of teeth; hence, pinions wear quicker than wheels.

Two teeth on a pinion or wheel is the minimum number in gear at one time, each bearing half the total load.

The *power* capable of being transmitted by gearing depends, within reasonable limits, entirely upon the *speed;* the *pressure* (at pitch line) depends upon the *pitch.*

The speed should not exceed 1800 feet per minute circumferential velocity for ordinary cast-iron wheels, or 2400 for mortise wheels.

The velocities of geared wheels are in the inverse ratio of their diameters.

The transmission of the power strains the teeth as cantilevers, or $s = \frac{b\,d^2}{l}\,c$, $c$ for cast iron safe load $= 600$.

The working load should not exceed $\frac{1}{10}$ of the breaking weight.

The dimensions of the teeth are proportional to the pitch; hence, in ordinary proportions the strength is represented by $p^2\,c$, $c$ for cast iron being 1000 as a maximum.

The breadth of tooth on face beyond a certain amount, say twice the pitch, cannot be reckoned upon for strength, owing to irregularities in the teeth, and probability of unequal bearing.

## 331. Strength and Weight of Toothed Gearing.

Safe pressure in lbs. at pitch line on wheel teeth of average proportions:—

| | | |
|---|---|---|
| Cast iron, | little shock | $= 625 \times \text{pitch}^2$. |
| „ | moderate shock | $= 400 \times \text{pitch}^2$. |
| „ | excessive shock | $= 277 \times \text{pitch}^2$. |

The latter case also applies to the iron teeth of mortise wheels, which are made thinner than ordinary teeth of same pitch.

J. B. Francis' rule for pitch $= \cdot 044 \sqrt{\text{lbs. pressure}}$.

Breadth of teeth $= 2$ to $2\frac{1}{2}$ times pitch.

The weight of toothed gearing in lbs. approximately, is for spur wheels $\cdot 38\, n\, b\, p^2$, bevel wheels $\cdot 325\, n\, b\, p^2$, where $n$ is number of teeth, $b$ breadth on face, and $p$ pitch.

## 332. Formulæ for Strength of Gearing.

$s$ = strain in lbs. to be transmitted, calculated at pitch circle.

$p$ = pitch in inches.

$c$ = constant, when teeth of ordinary proportion =

| Material. | Plain. | Shrouded. |
|---|---|---|
| Cast steel . . . | 4000 | 6000 |
| Wrought iron . . | 3000 | 4500 |
| Malleable cast iron . | 2000 | 3000 |
| Gun metal . . . | 1500 | 2000 |
| Cast iron . . . | 1000 | 1500 |

$$s = p^2 c. \qquad p = \sqrt{\frac{s}{c}}.$$

For slow speeds and uniform pressure $c$ may be increased one-fourth.

### 333. Wheel Gearing, Manchester Pitch.

Diametral pitch (Manchester pitch)

$$= \frac{\text{No. of teeth}}{\text{diameter of pitch circle in inches}}.$$

$$\text{Circular pitch} = \frac{\pi}{\text{diametral pitch}},$$

or (tooth + space) in inches.

No. of teeth in wheel = diameter × diametral pitch.

$$\text{Diameter of wheel} = \frac{\text{No. of teeth}}{\text{diametral pitch}}.$$

Addition to diameter for increased No. of teeth

$$= \frac{\text{No. to be added}}{\text{diametral pitch}}.$$

Outside diameter of wheel

$$= \frac{2}{\text{diametral pitch}} + \text{diameter pitch circle.}$$

For example:—A 10-pitch wheel (Manchester or diametral pitch) 7·5 inches diameter will have $10 \times 7{\cdot}5 = 75$ teeth; another in the same set 4 inches in diameter would have $10 \times 4 = 40$ teeth, and their true pitch would be

$$\frac{3{\cdot}1416 \times 7{\cdot}5}{75} = \frac{3{\cdot}1416 \times 4}{40} = {\cdot}31416 \text{ inches},$$

or generally, with $n$-pitch wheels, true pitch $= \frac{\pi}{n}$ inches.

### 334. Mill Gearing.

| | |
|---|---|
| $H$ = H.P. actual. | $p$ = pitch inches. |
| $b$ = breadth on face inches. | $R$ = revolutions per minute. |
| $D$ = diameter in feet. | $n$ = No. of teeth. |

$$H = \frac{p^2 b D R}{306}. \qquad p = \sqrt{\frac{306 H}{b D R}}.$$

$$D = p \operatorname{cosec} \frac{180^\circ}{n}. \qquad p = \frac{D}{\operatorname{cosec} \frac{180^\circ}{n}}.$$

Another formula:

$$\text{N.H.P.} = \sqrt{(D\,R)} \times p^2 b \times \begin{cases} \cdot 05 \text{ wood} \\ \cdot 043 \text{ cast iron} \\ \cdot 15 \text{ cast steel} \end{cases}$$

Gudgeons (*Tredgold*):

$$\text{Diameter inches} = \frac{\sqrt{w \text{ lbs.} \times l \text{ inches}}}{9}.$$

### 335. Speed of Mill Gearing.

Maximum safe speeds under favourable conditions for toothed gearing:

| | |
|---|---|
| Ordinary cast-iron wheels . . . | 1800 ft. per min. |
| Helical " " . . . | 2400 " |
| Mortice " " . . . | 2400 " |
| Ordinary cast-steel wheels . . . | 2600 " |
| Helical " " . . . | 3000 " |
| Special cast-iron machine-cut wheels . | 3000 " |

—*A. Towler.*

### 336. Determining the Proportions of Gearing.

In toothed gearing exact ratios should be sacrificed to obtain numbers prime to each other. When the wheels are to be equal, one of them should have an additional tooth called a "hunting-cog"; then each tooth of the one will encounter each tooth of the other, equally often, and equalise the wear.

Numbers are prime to each other when they have no common measure, i.e. cannot both be divided without remainder by any number except 1.

For wheels to gear properly the number of teeth in each must be proportionate to their diameters—in other words, their pitch must be equal.

### 337. Proportions of Wheel Teeth.

| | Parts. | Per Cent. | Other Authorities. | | |
|---|---|---|---|---|---|
| Pitch | 15 | or 100 | 100 | 100 | 100 |
| Whole length of tooth | 12 | „ 80 | 60 | 75 | 75 |
| Pitch line to point | $5\frac{1}{2}$ | „ 36·6 | 25 | 33 | 35 |
| „ to root | $6\frac{1}{2}$ | „ 43·3 | 35 | 42 | 40 |
| Thickness at pitch line | 7 | „ 46·6 | 48 | $48\frac{1}{2}$ | 45 |
| Width of space at ditto | 8 | „ 53·3 | 52 | $51\frac{1}{2}$ | 55 |

| | |
|---|---|
| Curve | radius = pitch, or cycloidal. |
| Breadth of tooth on face | 250 per cent. |
| Thickness of rim | 44 to 50 |
| Projecting ribs inside ditto | 44 to 50 |
| Thickness of arms | 44 to 50 |
| Breadth of arms at rim | 175 |
| „ of taper increasing to boss | $\frac{1}{2}$ inch per foot |
| Thickness of rib on arms | 25 |
| „ metal in boss | 75 to 80 |

### 338. Ordinary Proportions of Keys.

$$\text{Width of key} = \begin{cases} \frac{1}{4} \text{ diam. of shaft up to 4 inches.} \\ \frac{1}{5} \quad „ \quad „ \quad \text{4 inches to 8 inches.} \\ \frac{1}{6} \quad „ \quad „ \quad 8 \quad „ \quad 12 \quad „ \end{cases}$$

Key square at thick end. Taper $\frac{1}{4}$ inch per foot.
One-third of thickness let in shaft, remainder in wheel.

### 339. Proportions of Cotters through Bars.

$b$ = Breadth of cotter.
$t$ = Thickness of cotter.
$d$ = Diameter of bar.

Through round bars,

$$b = 1 \cdot 4635\, d. \qquad t = \frac{d}{5}.$$

Through square bars,

$$b = 1 \cdot 5 \text{ side of bar.} \qquad t = \frac{\text{side of bar}}{4}.$$

### 340. Journals for Shafts and Axles.

Length of brass = 0·9 to 1·0 length of journal. Less liable to score in wearing, if slight end play can be given.

Thickness and projection of collar and radius of curves

$$= \frac{d}{8} + \frac{1}{8}\text{ in. to } \frac{d}{10} + \frac{1}{8}\text{ in.}$$

### 341. Power of Craneman, &c.

| | |
|---|---|
| Radius of handle . . . . . | 1 ft. 3 in. to 1 ft. 6 in. |
| Height to centre of axle . . . . | 2 „ 6 „ 3 „ 0 „ |
| Height from ground to path of handle | 1 „ 6 „ 1 „ 9 „ |
| Revolutions of handle per minute . . . . | 28 to 23 |
| Speed at circumference of handle for continuous work while lifting . | 220 feet per minute |
| Do. do., when lifting and lowering . | 330 „ „ |
| Force of ordinary labourer on handle | 12 lbs. + friction |
| „ „ craneman „ . | 15 „ „ |
| Maximum ditto, for short time, say 5 minutes, at 440 feet per minute | 30 „ „ |

At 8 hours per day, on long lifts, the effective work averages 2380 to 2420 foot-lbs. per minute per man.

One man can raise 1 ton with a multiplying power of 150, the friction being about 6½ lbs., and the effective pressure 15 lbs., making the gross pressure on the handle 21½ lbs., or coefficient = ·7.

Speed of lifting with hand-power crane = 2 feet per second.

In raising weights with a pulley a man can maintain a downward pull of 40 lbs. permanently, and equal to his own weight temporarily.

### 342. Hand Power Crane.

$W$ = load in lbs.
$P$ = power required in lbs. to overcome load.
$F$ = friction of gearing of crane without load.
$f$ = friction of gearing due to load.
$M$ = multiplying power of gearing.
$E$ = efficiency of crane under various loads.

$$P = F + f + \frac{W}{M}.$$

$$E = \frac{W}{MP} = \cdot 5 \text{ to } \cdot 75.$$

By experiment with 10 cwt. crane—

$$M = 40, \quad F = 4{\cdot}21 \text{ lbs.}, \quad f = \cdot 0179\, W.$$

—*R. S. Ball.*

1 ton crane, 4 men at handles, 25 lbs. each man, multiplying power 24 to 1.

Delivery cranes, short lift, lowering by brake, allow 25 lbs. for each man, handle 16-inch radius, 30 revolutions per minute, coefficient ·75.

Landing cranes, long lift, allow 15 lbs for each man.

### 343. Crab Winches.

$R$ = radius of handle.
$r$ = radius of barrel to centre of rope.
$A$ = radius, diameter, or number of teeth in pinion.
$B$ = „ „ „ „ wheel.
$W$ = load lifted in lbs.
$P$ = power applied in lbs.
$M$ = modulus of efficiency, or coefficient, say ·75.

Single purchase crab,

$$W = P \times \frac{R}{r} \times \frac{B}{A} \times M.$$

Double-purchase crab,

$$W = P \times \frac{R}{r} \times \frac{B}{A} \times \frac{B_1}{A_1} \times M.$$

### 344. Rope Tackle for Lifting.

| | | | | | | |
|---|---|---|---|---|---|---|
| Diameter of sheave in inches | 3 | $3\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 5 | 6 |
| Circumference of rope in inches | 1 | $1\frac{1}{2}$ | 2 | $2\frac{1}{2}$ | 3 | 4 |
| Average strain on rope in cwts. for full load | 1 | $2\frac{1}{4}$ | $3\frac{3}{4}$ | 6 | $8\frac{1}{2}$ | 15 |
| Number of men required for full load | 1 | 3 | 6 | 10 | crab | crab |
| Maximum power in cwts— | | | | | | |
| 2 and 1 sheave | $2\frac{1}{4}$ | $4\frac{1}{2}$ | 9 | .. | .. | .. |
| 2 „ 2 „ | 3 | 7 | 12 | .. | .. | .. |
| 3 „ 2 „ | .. | $8\frac{3}{4}$ | 15 | 25 | 35 | 60 |
| 3 „ 3 „ | .. | $10\frac{1}{2}$ | $17\frac{1}{2}$ | 30 | 42 | 72 |
| 4 „ 3 „ | .. | .. | 20 | 35 | 49 | 84 |

With equal sheaves the fast end must be on top block; unequal on bottom. Snatch block makes practically no difference if the rope has a good lead. Larger blocks than 6 inches should have chain fall. Blocks 4 inches to 6 inches may have rope or chain.

### 345. Safe Load on Shear Legs and Derrick Poles.

D = inches diameter at bottom.
$d$ = „ „ top.
L = length in feet.
R = rake or overhang in feet.
W = safe load in tons per pole.

$$\text{Approximate } W = \frac{3\,D\,d}{L + R}.$$

### 346. Differential Pulley Calculations.

D = diameter of larger pulley. $d$ = diameter of smaller pulley.

$$D : \frac{D - d}{2} :: W : P \quad \therefore P = \frac{W \times (D - d)}{2\,D}.$$

$M$ = modulus or efficiency of machine, then $W \times M$ = actual load lifted. Load will not lower by itself when $M$ is less than ·5.

By experiment with various differential pulleys—

| Load. | Multiplying Power. | Coefficient. |
|---|---|---|
| 5 cwt. | 16 to 1 | ·4 |
| 10 „ | 30 „ 1 | ·33 |
| 30 „ | 53 „ 1 | ·25 |

# SECTION VIII.

# FRICTION AND LUBRICATION.

## 347. Laws of Friction.

The friction between two surfaces, dry or only slightly greasy, is in direct proportion to the force with which they are pressed together (within the limits of abrasion), and is independent of the area of the surfaces in contact. With ample lubrication the friction is reduced, but the heavier the pressure per unit of surface the greater must be the consistency of the lubricant, to prevent it from being squeezed out.

The friction between two surfaces at rest is slightly greater than when they are in motion, but when in motion the friction is independent of the velocity so long as the surfaces are kept cool.

Friction is not a force; being passive, it can only act as a resistance.

The laws of friction are sometimes stated as follows:—

*First Law of Friction.*—The friction is proportional to the pressure when the surfaces are the same.

*Second Law of Friction.*—Friction is independent of the area of the surfaces in contact.

## 348. Angle of Repose

is the angle ($\phi$) made by a flat surface with the horizontal when a weight just ceases to move down it by gravity. The corresponding coefficient of friction ($\tan\ \phi$) is the

fraction of the weight required as pressure just insufficient to produce motion on a horizontal plane.

| Angle. | Coeff. | Angle. | Coeff. | Angle. | Coeff. |
|---|---|---|---|---|---|
| $1\frac{3}{4}^\circ$ = | ·03 | $13^\circ$ = | ·23 | $19\frac{1}{2}^\circ$ = | ·35 |
| 2 = | ·04 | $13\frac{1}{2}$ = | ·24 | 20 = | ·36 |
| 3 = | ·05 | 14 = | ·25 | $26\frac{1}{2}$ = | ·50 |
| 4 = | ·07 | $14\frac{1}{2}$ = | ·26 | 28 = | ·53 |
| $4\frac{1}{2}$ = | ·08 | 15 = | ·27 | $29\frac{1}{2}$ = | ·57 |
| $8\frac{1}{2}$ = | ·15 | $16\frac{1}{2}$ = | ·30 | 31 = | ·60 |
| $11\frac{1}{2}$ = | ·20 | $18\frac{1}{2}$ = | ·33 | 35 = | ·70 |

## 349. Definitions of Friction.

*The Limiting Angle of Resistance* $\phi$ is the angle through which any surface requires to be lifted from the horizontal to cause a body to be on the point of sliding (friction of rest) or to continue sliding (friction of motion). Its magnitude is fixed by the physical nature of the surfaces in contact. It is also the angle from the vertical made by the resultant of the force or forces acting upon a body when sliding is just about to take place or is taking place.

*The Coefficient of Friction* $\mu$ is the ratio of the pressure P required to overcome the friction of a body on any given horizontal surface, to the whole load W of and on the body $\left(\mu = \frac{p}{W}\right)$. Trigonometrically it is equal to the tangent of the limiting angle of resistance ($\mu = \tan \phi$).

It has been proposed to call the "friction of rest" *stiction*, to distinguish it from the "friction of motion," which would be called *friction*. The common term for the "friction of rest" is statical friction.

## 350. Morin's Experiments on Friction of Motion.

*Dry:*

| | | | |
|---|---|---|---|
| Wrought iron on brass | ·172 | Brass on wrought iron | ·161 |
| Cast " " | ·147 | " cast " | ·217 |

*Greasy:*

| | | | |
|---|---|---|---|
| Wrought iron on brass | ·160 | Brass on wrought iron | ·166 |
| Cast „ „ | ·132 | „ cast „ | ·107 |
| *Lubricated with olive oil:* | | | |
| Wrought „ „ | ·078 | „ wrought „ | ·072 |
| Cast „ „ | ·078 | „ cast „ | ·077 |

Oak upon elm dry = $\frac{5}{9}$ of friction of elm upon oak dry.

*Note.*—These results reduced from General Morin's experiments appear to be very questionable, and indicate the necessity for further investigation.

### 351. Safe Working Pressure on Moving Surfaces.

$v$ = velocity feet per second.
$p$ = pressure lbs. per square inch.

$$p = \frac{2240}{3\,v + 1},$$

but $p$ must not in any case exceed 1200. —*Rankine.*

### 352. Experiments on Friction.

Pine upon pine, grain crossed, slide 9 inches × 9 inches, load 14 to 112 lbs. in motion.

$$\mu\,W = 1 \cdot 44 + \cdot 252\,W.$$ —*Prof. Ball.*

In an experiment with a hand brake on the tender of a locomotive on the Northern Railway of France, it was found that 82·3 per cent. of the whole power applied was absorbed by friction before reaching the brake block.

### 353. Friction and Heat.

Friction of any kind, however produced, results in the conversion of mechanical work into heat. One horse-power or 33,000 foot-lbs. of work per minute expended in friction produces $\frac{33,000}{772}$ = 43 British thermal units per minute.

## 354. Friction of Journals.

Coefficient of friction ($\mu$), average ·08; but under favourable conditions may be as low as ·01.

Work expended in friction in foot-lbs. per minute =

$$\mu \, W \frac{\pi}{12} d \, R = \cdot 021 \, W \, d \, R.$$

Heat units to be dissipated per minute $= \frac{U}{J}$ ($J = 772$).

Length of journal depends upon the load and speed, length being increased for high speeds.

$$l = \frac{W(50 + \text{velocity in feet per minute})}{70{,}000 \, d.} \; (\textit{Bourne}),$$

or

$$l = d(\cdot 004 R + 1) \; (\textit{Unwin}).$$

$$l = \frac{W R}{250{,}000, \text{ to } 300{,}000},$$

or

$$l = \cdot 4 \text{ to } \cdot 33 \frac{\text{I.H.P.}}{\text{rad. crank inches}}.$$

Increasing diameter increases friction, because the rubbing surface has further to travel in one revolution.

Increasing length reduces the friction per square inch, but does not affect the total friction, because for a given space passed through, with a constant load, the friction is independent of surfaces in contact.

The "bearing area" is taken to be the length × diameter.

When an overhanging journal is increased in length the diameter must also be increased slightly, to give same strength as before, $D = d\sqrt[3]{\frac{L}{l}}$. Pressure on bearings in lbs. per square inch longitudinal section may be

$$= \frac{70{,}000}{50 + \text{velocity in feet per minute}},$$

but must never exceed 1000, maximum say 800 in slow-running engines, down to 400 lbs. in quick speed engines.

### 355. Shop Shaft Bearings.

Allowing 1 square inch per thermal unit per minute.

P = load in lbs.
$\mu$ = frictional coefficient (say ·02).
S = surface speed feet per minute.
J = Joule's equivalent = 772.
T = thermal units evolved per minute.
$d$ = diameter of shaft in inches.
$l$ = length of bearing in inches.

$$T = \frac{P \mu S}{J}, \qquad l = \frac{T}{d}.$$

—*Prof. Goodman.*

### 356. Mean Coefficients of Friction.

Wood on wood or metal—dry, ·4 to ·6; greasy, ·2 to ·4; lubricated, ·1 to ·2.

Metal on metal—wet, ·3; dry, ·2; greasy, ·15; lubricated, ·1 standing, or ·08 moving.

Leather on metal—wet, ·25; dry, ·5.

Friction of motion = friction of repose × ·7.

Friction varies with the nature of the surfaces, the lubricant, and the temperature.

Unguents should be thick for heavy pressures, that they may resist being forced out; and thin for light pressures, that their viscidity may not add to the resistance.

—*Rankine.*

In estimating the power to overcome friction, the friction of rest must be taken; but in estimating the effect of friction as a power to resist motion, say a brake strap, the friction of motion must be taken.

## 357. Lubricants for Various Cases.

Under very great pressure with slow speed:—Graphite, soapstone, tallow and other greases.

Under heavy pressure and high speed:—Sperm oil, castor oil and heavy mineral oils.

Under light pressures and high speed:—Sperm oil, refined petroleum, olive, rape and cotton-seed oil.

Ordinary machines:—Lard oil, heavy mineral and other vegetable oils.

Steam cylinders:—Heavy mineral oils. —*Rallings.*

## 358. Action of Oils on Metals.

The results of twelve months' experiments, by Prof. Redwood, show that—

*Iron* is least affected by seal oil, very little by rape oil, and most by tallow oil.

*Brass* is not affected by rape oil, least by seal oil, and most by olive oil.

*Tin* is not affected by rape oil or whale oil, least by olive oil, and most by cotton-seed oil.

*Lead* is least affected by olive oil, and most by whale oil; but whale, lard and sperm oils all act to very nearly the same extent on lead.

*Zinc* is not acted on by mineral lubricating oil, least by lard oil, and most by sperm oil.

*Copper* is not affected by mineral lubricating oil, least by sperm oil, and most by tallow oil.

*Mineral Lubricating Oil* has no action on zinc and copper, acts least on brass, and most on lead.

*Olive Oil* acts least on tin and most on copper.

*Rape Oil* has no action on brass and tin, acts least on iron, and most on copper.

*Tallow Oil* acts least on tin and most on copper.

*Lard Oil* acts least on zinc and most on copper.

*Cotton-seed Oil* acts least on lead and most on tin.

*Sperm Oil* acts least on brass and most on zinc.

*Whale Oil* has no action on tin, acts least on brass, and most on lead.

*Seal Oil* acts least on brass and most on copper.

From the foregoing results it will be seen that mineral lubricating oil has, on the whole, the least action on the metals experimented with, and sperm oil the most.

For lubricating the journals of heavy machinery, either rape or sperm oil is the best oil to use in admixture with mineral oil, as they have the least effect on brass and iron, which two metals generally constitute the bearing surfaces of an engine. Tallow oil should be used as little as possible, as it has considerable action on iron.

### 359. Rolling Friction

is directly as the pressure, and inversely as the diameter of the rolling bodies.

### 360. Traction, or Friction on Roads.

Cart on common road $= \frac{1}{30}$ load.
Carriage on plank road $= \frac{1}{100}$ „
„ on railroad $= \frac{1}{300}$ „

## SECTION IX.

# THERMODYNAMICS, AND STEAM.

### 361. Imponderables.

Light, heat, electricity and magnetism were formerly supposed to be material substances without weight, and were known as "imponderables"; they are now considered as modes of motion.

### 362. Universal Ether.

Sound waves require air for their transmission through space; heat and light are independent of air in their passage, and may be transmitted across a vacuum. It is therefore supposed that there is a medium, more rarefied than air, pervading all space, which transmits waves of heat and light as air does sound.

### 363. Rankine's Dynamical Theory of Heat.

Each atom of matter consists of a nucleus or central physical point enveloped in an elastic atmosphere, which is retained in its position by forces attractive towards the nucleus or centre.

The elasticity due to heat arises from the centrifugal force of revolutions or oscillations among the particles of the atomic atmospheres; so that quantity of heat is the *vis viva* of those revolutions or oscillations.

The medium which transmits light and radiant heat consists of the nuclei of the atoms vibrating independently, or almost independently, of their atmospheres. So that the absorption of light and radiant heat is the transference of

motion from the nuclei to their atmospheres, and the emission of light and radiant heat the transference of motion from the atmospheres to their nuclei.

### 364. Sources of Heat.

Friction, Percussion, Mechanical stress, Chemical action, Electrical action.

### 365. Sensible Heat.

The *Temperature* of a body is its thermal state considered with reference to its power of communicating heat to other bodies. —*Clerk Maxwell.*

This is commonly called its sensible heat.

For purposes of measurement some definite effect produced by heat must be selected, e.g. the alteration in length or volume of a substance which expands and contracts uniformly when heated or cooled.

At all ordinary temperatures the ratio of increment in volume to increment in absolute temperature is practically constant in the case of mercury; it is, moreover, a liquid at such temperatures, and easily measured; hence the *Mercurial Thermometer* is that most commonly used for determining the temperature of a body.

### 366. Comparison of Thermometers.

| — | No. of Degrees between Freezing and Boiling Point of Water. | Absolute Zero of Temperature.* | Freezing Point of Water. | Point of Maximum Density of Water. | Boiling Point of Water. |
|---|---|---|---|---|---|
| Great Britain and America: Fahrenheit = F. . . | 180 | −461·2† | 32 | 39·1 | 212 |
| Sweden, France, &c.: Centigrade or Celsius = C. | 100 | −274 | 0 | 4 | 100 |
| Russia and Spain: Réaumur = R. . . | 80 | −219·2 | 0 | 3·2 | 80 |

* Or point of absolute negation of heat. † Box — 458·4, Goodeve — 459·13.

$$\therefore \quad 9^\circ \text{ F.} = 5^\circ \text{ C.} = 4^\circ \text{ R.}$$

To convert from one scale to another:

$$F^\circ = \tfrac{9}{5}\,C^\circ + 32,\ C^\circ = \tfrac{5}{9}(F^\circ - 32),\ R^\circ = \tfrac{4}{9}(F^\circ - 32),$$
$$F^\circ = \tfrac{9}{4}\,R^\circ + 32,\ C^\circ = \tfrac{5}{4}\ R^\circ,\qquad R^\circ = \tfrac{4}{5}\ C^\circ.$$

### 367. Effect of Change of Temperature.

All bodies expand by heat and contract by cold, i.e. expand by addition of heat and contract by loss of heat; more precisely—change of temperature alters the relation between the attractive and repulsive forces of the atoms of a solid body, and therefore alters the distance at which they would remain in equilibrium, neither attracting nor repelling each other. In the case of gases, the atoms repel each other at all temperatures, and the effect of a change of temperature is to alter the amount of the repulsive force and pressure upon the containing vessel, increasing them with increase of temperature, and *vice versâ.*

### 368. Transfer of Heat.

*Radiation* of heat is the transfer which takes place between bodies at all distances apart, in the same manner and according to the same laws as the radiation of light.

The intensity of radiant heat diminishes as the square of the distance from the radiating body.

*Conduction* is the transfer of heat between two bodies, or parts of a body, which touch each other.

*Convection*, or carrying of heat, means the transfer and diffusion of the state of heat in a fluid mass by means of the motion of the particles of that mass.

### 369. Mechanical Equivalent of Heat.

*British Thermal Unit*, or unit of heat, is the quantity of heat required to raise 1 lb. of pure water, at its point of maximum density ($= 39 \cdot 1^\circ$ F.), through $1^\circ$ F.

*Joule's Equivalent* (J) is the mechanical effect resident in one thermal unit = 772 foot-lbs. By Micalesco's experiments, with modern appliances, a closer value would seem to be $772 \cdot 3$ foot-lbs.

By Chase's value of $\gamma$ (= the ratio of specific heats of gases = 1·405,285), Prof. Thurston makes J = 778·12 foot-lbs., or 427 kilogrammetres per calorie.

When the centigrade scale is used, the point of maximum density of water will be 4° C., the thermal unit the quantity of heat required to raise 1 lb. water through 1° C., and its mechanical equivalent 1390 foot-lbs.

*The Quantity of Heat* involved in any operation may be expressed directly by its mechanical equivalent in foot-lbs.

### 370. Calorie or French Unit of Heat.

A calorie represents the heat required to raise 1 kilogramme of pure water 1° C. from its point of maximum density 4° C. A calorie is equal to nearly four British heat units = C.

$$\frac{\text{British thermal units}}{3 \cdot 96832} = \text{French thermal units.}$$

$$\frac{\text{French thermal units}}{0 \cdot 251996} = \text{British thermal units.}$$

By other writers, especially on elasticity, a calorie is said to be the amount of heat required to raise 1 gramme, &c. = $3\frac{1}{10}$ foot-lbs. This is made = $c$.

### 371. Mayer's Experiment.

Dr. Mayer of Heilbronn found that 1 cubic foot of air at 32° F., 14·7 lbs. pressure, heated to 525·2° F., expansion being prevented, requires 6·73 units of heat. Heated to same temperature with expansion under constant pressure requires $6 \cdot 73 + 2 \cdot 746 = 9 \cdot 476$ units, and volume will be doubled (as the temperature is raised from $32 + 461 \cdot 2 = 493 \cdot 2$ to $525 \cdot 2 + 461 \cdot 2 = 986 \cdot 4$ and $986 \cdot 4 \div 493 \cdot 2 = 2$). The pressure of 1 atmosphere or 2116·3 lbs. on square foot is moved through 1 foot, or 2116·3 foot-lbs. of work has been done, and 2116·3 being divided by 2·746, the units of heat which have disappeared, we obtain 770·7 foot-lbs. as the

mechanical equivalent of 1 unit of heat. Although the 2·746 units of heat cease to exist as sensible heat, they cannot be called latent as they are transformed into work.

### 372. Entropy.

*Entropy* (Clausius, 1848) *Thermodynamic Function* (Rankine) is such a quantity as, multiplied by absolute temperature, will give the capacity which heat has theoretically of performing mechanical work.

Mechanical work, electricity, and heat are different forms of energy. Mechanical work is measured by foot-lbs., being the product of the force in lbs. into the space in feet through which it acts. Electrical energy is measured by the watt, being the product of the intensity of current in volts into the quantity of current in ampères. The same requirement applies to heat energy; the intensity is measured by temperature and the quantity by entropy.

Entropy has been described by Prof. Dwelshauver-Dery as a heat scale which varies with the absolute temperature, as gravity varies on the surface of the earth with the distance from the centre.

### 373. Capacity of Bodies for Heat.

*Capacity for heat* (Irvine) of a body is the number of units of heat required to raise one pound weight of the body one degree in temperature.

### 374. Specific Heat.

The *Specific Heat* (Gadolin) of a body is its capacity for heat compared with that of an equal weight of water. It is the quantity of heat requisite to change its temperature any stated number of degrees ($= a$) compared with that which would produce the same effect on water at 60° F. and 30 inch barometer ($= b$), and it is therefore expressed by the fraction $\frac{a}{b}$, which may be made referable to weight or volume.

If a unit mass of a substance absorbs a quantity of heat $q$ in passing from a temperature T, to a temperature $T + t$, then the ratio $q / t$ is termed the *mean specific heat for $t°$ from the temperature* T.

The limit of the ratio $q / t$, as $t$ is diminished, is termed the *true specific heat at the temperature* T.

The specific heat of all bodies (except gases) increases slightly with the temperature. The specific heat of a gas at constant pressure under which it expands, is greater than at constant volume.

### 375. Dulong and Petit's Law.

*Dulong and Petit's Law* (1819).—The specific heats of the chemical elements are inversely proportional to their atomic weights, so that their product is in all cases constant. It is generally expressed as, "the atoms of all elementary bodies have the same specific heat."

Neumann, Regnault and Kopp have shown that this law applies to compounds as well as elements, the specific heat of a compound being the sum of the specific heats of its component elements.

### 376. Specific Heats of Various Bodies.

| | | |
|---|---|---|
| Specific heat of water at 39·1° F. . | = | 1 |
| „ iron . . . . | = | ·114 |
| „ air at constant pressure | = | ·238 |
| „ air at constant volume | = | ·169 |
| „ steam gas at constant pressure . . . | = | ·475 |
| „ steam gas at constant volume . . . | = | ·37 |

The specific heat of saturated steam (= ·305) is the quantity by which the total heat of steam is increased for each degree of temperature.

Thermal units required to raise any body $t°$ in temperature = weight × specific heat × $t°$.

### 377. Latent and Total Heat.

*Latent heat* (Black 1757) is the heat absorbed or disengaged by a body without alteration of temperature, upon a change of state or alteration in the aggregation of its molecules. Approximately the latent heat of steam = 1115 − ·7 times sensible heat F°.

Ice in melting absorbs as much heat as would raise the same weight of water at 32° F. to 174·65° F.

Water in evaporating from 212° F. absorbs as much heat as would raise 966 times the quantity 1° F., or six times the quantity from 51° F. to 212° F.

*Total heat.*—Dr. Black's theory of the latent and sensible heat of steam was that the sum of the two was constant at all temperatures.

Regnault's experiments showed that the total heat was not constant, but increased slowly with increase of temperature, and was equal in F.° to

$$\{(\text{Sensible temperature in F.}^\circ - 32) \times {\cdot}305\} + 1123{\cdot}7.$$

Approximately the total heat of steam = 1115 + ·3 times sensible heat F°.

### 378. Gases and Vapours.

*Permanent gases* are constant elastic fluids which cannot be liquefied.

The temperature being constant, the volume of a gas is inversely as its pressure.

The product of the volume and pressure of any gas is proportional to the absolute temperature.

$$\left.\begin{array}{l} v = \text{volume of a perfect gas} \\ t = \text{absolute temperature} \\ p = \quad ,, \quad \text{pressure} \end{array}\right\} \frac{v\,p}{t} = \text{constant.}$$

In raising the temperature of a gas under constant pressure, mechanical work is done in providing the necessary space for its expansion.

When a gas is heated, the expansion is about $\frac{1}{273}$ of its volume at 0° C. for each degree C. increase of temperature, or permanent gases expand ·00202 of volume for each F.° increase of temperature from 32° F. under a constant pressure.

*Ordinary gases* are those which do not liquefy at ordinary temperatures or pressures, and the farther they are removed from their point of liquefaction the nearer they approach the character of permanent gases.

*Vapours* are gases near their point of liquefaction. Ordinary high or low pressure steam is a vapour, superheated steam is a gas.

Vapour of water is absorbed by the air at all temperatures, the higher the temperature of the air the more water it is capable of holding in solution.

### 379. Kinetic Theory of Gases.

A gaseous body consists of a swarm of innumerable solid particles incessantly moving about with different velocities in rectilinear paths of all conceivable directions, the velocities and directions being changed by mutual encounters at intervals which are short in comparison with ordinary standards of duration, but indefinitely long as compared with the duration of the encounters.

"Gases consist of atoms which behave like solid, perfectly elastic spheres moving with definite velocities in void space."

—*Kroenig.*

A gas consists of a number of molecules, flying in straight lines, and impinging like little projectiles not only on one another, but also on the sides of the vessel holding the gas. Gases of every kind will diffuse into each other. It is thought that the velocity of a molecule of hydrogen at 32° F. and at the atmospheric pressure is 6097 feet per second.

—*Goodeve.*

## 380. Laws of Gases.

*Boyle's Law* (1662), also enunciated by *Marriotte* (1676) The volume of a gas varies inversely as the pressure. It may also be stated thus: the pressure of a gas is proportional to its density. The law is most nearly fulfilled when the temperature of the gas is farthest removed from its point of condensation.

*Charles' Law* (1787). All gases expand equally, and the volume varies directly as the absolute temperature.

*Dalton* (1801). A gas at any temperature increases in volume for a rise of 1° by a constant fraction of its volume at that temperature.

*Gay-Lussac* (1802). The augmentation of volume which a gas receives when the temperature increases 1° is a certain fixed proportion of its initial volume at 0° C.

Under a constant pressure all gases expand uniformly with equal additions of heat, and with a constant volume all gases increase equally in pressure for equal increments of heat.

*Avogadro's Law* (1811), also attributed to *Ampère* and *Gay-Lussac.* Equal volumes of all substances, when in the gaseous state and under like conditions of pressure and temperature, contain the same number of molecules.

Boyle's is sometimes called the first law of gases, and Charles' the second law.

## 381. Volume of a Gas at Given Pressure and Temperature.

V = volume of gas at T° and P lbs.

$v$ = " " $t°$ " $p$ lbs.

$$v = \mathrm{V} \times \frac{458 \cdot 4 + t}{458 \cdot 4 + \mathrm{T}} \times \frac{\mathrm{P}}{p}.$$

—*Box, on 'Heat.'*

$v$ = volume of elastic fluid given weight and pressure at 32° F.

V = volume it will occupy at same pressure at $t$° F.

$$V = v + \cdot 00202\, v\,(t - 32).$$

—*Gay Lussac.*

The volume of a gas under constant pressure expands 1·3665 times when raised from 32° to 212° F.

### 382. Pressure and Temperature of Steam.

$p$ = lbs. per square inch.
$t$ = temperature F°.

1 to 24 atmospheres:

$$p = (\cdot 2697 + \cdot 006803\, t)^5.$$
$$t = 147 \sqrt[5]{p} - 39 \cdot 644.$$

—*Arago and Dulong.*

1 to 4 atmospheres:

$$p = \left(\frac{103 + t}{201 \cdot 18}\right)^6.$$
$$t = 201 \cdot 18 \sqrt[6]{p} - 103.$$

Up to 90 lbs. per sq. inch:

$$p = \tfrac{1}{2}\left(\frac{t + 100}{177}\right)^6.$$
$$t = 177\,(\sqrt[6]{2p}) - 100.$$

—*Tredgold.*

1 to 4 atmospheres:

$$p = \left(\frac{98 \cdot 8 + t}{198 \cdot 56}\right)^6.$$
$$t = 198 \cdot 56 \sqrt[6]{p} - 98 \cdot 8.$$

—*De Pambour.*

383. Relation of Pressure to Temperature.

$p$ = original pressure (absolute).
$t$ = „ temperature (F°).
$p_1$ = new pressure.
$t_1$ = new temperature.

$$p_1 = p\left(\frac{t_1}{t}\right)^{4\cdot 4}.$$

$$t_1 = t\sqrt[4\cdot 4]{\frac{p_1}{p}}.$$

384. Pressure and Volume of Steam by Boyle and Marriotte's Law.

P = original pressure.
$p$ = new pressure.
V = original volume.
$v$ = new volume.

$$p = \frac{\mathrm{P\,V}}{v}, \qquad v = \frac{\mathrm{P\,V}}{p}.$$

385. Relative Volume of Steam.

The ratio of the volume of steam to that of the water from which it is produced is called the relative volume.

$p$ = total pressure in lbs. per square inch.
$t$ = temperature in F°.
V = relative volume for pressures between 6 and 60 lbs.

$$\mathrm{V} = 37\,\frac{460 + t}{p}, \qquad t = 147\sqrt[5]{p} - 40.$$

By *Boyle and Marriotte's law.*

With constant temperature the volume varies inversely as the pressure ∴ volume × pressure = constant.

$$\mathrm{V \ approximately} = \frac{25{,}000}{p}.$$

N 2

By *Navier's modification.*

The temperatures not being constant, in ordinary cases for varying pressures.

$$V \text{ up to 26 lbs. per square inch} = \frac{27{,}000}{p+1}.$$

$$V \text{ above} \quad ,, \quad ,, \quad = \frac{30{,}000}{p+4}.$$

By *Pole's formula.*

$$V = \frac{24{,}250}{p} + 65, \qquad p = \frac{24{,}250}{v - 65}.$$

By *Hann's formula.*

$$V = \frac{17{,}149 + 37\,t}{p}.$$

### 386. Saturated Steam.

Vapour in a closed space in contact with the generating liquid is said to be *saturated*, i.e. some portion will liquefy upon the smallest increase of pressure or reduction of temperature.

### 387. Properties of Saturated Steam.

| Absolute Pressure. | Gauge Pressure. | Sensible Temperature. | Latent Heat. | Total Heat. | Weight of Cubic Foot. | Relative Volume. |
|---|---|---|---|---|---|---|
| lbs. | lbs. | deg. F. | | | lbs. | |
| 14·7 | 0·0 | 212·0 | 966·1 | 1178·1 | ·0380 | 1642 |
| 65 | 50·3 | 298·0 | 906·3 | 1204·3 | ·1538 | 405 |
| 70 | 55·3 | 302·9 | 902·9 | 1205·8 | ·1648 | 378 |
| 75 | 60·3 | 307·5 | 899·7 | 1207·2 | ·1759 | 353 |
| 90 | 75·3 | 320·2 | 890·9 | 1211·1 | ·2089 | 298 |
| 115 | 100·3 | 338·0 | 878·5 | 1216·5 | ·2628 | 237 |
| 135 | 120·3 | 350·1 | 870·1 | 1220·2 | ·3060 | 203 |
| 165 | 150·3 | 366·0 | 858·9 | 1224·9 | ·3695 | 169 |
| 215 | 200·3 | 388·0 | 843·7 | 1231·7 | ·4707 | 132 |

### 388. Atmospheric Pressure.

The weight of the atmosphere at 60° F. and 30 inches barometric pressure is 14·6757 lbs. per square inch.

Number of atmospheres $\times$ ·006557 = tons per sq. inch.

Absolute pressure is the pressure from zero, or the pressure of the atmosphere added to the indication of the pressure gauge, say gauge pressure + 15 lbs.

All questions of expansion and compression of steam must be worked from absolute pressure or perfect vacuum line of indicator diagram.

1 lb. of air at 32° F. and 30 in. bar. = 12·384 cubic feet.

To find work done by steam in repelling air during formation:

1 lb. water occupies ·016 cubic foot.

·016 $\times$ relative volume = space occupied by steam.

Steam space − ·016 = augmentation of volume.

$$\frac{\text{lbs. per sq. in. abs. press.} \times 144 \times \text{aug. vol.}}{772} = \text{units heat.}$$

### 389. Expansion Curves.

An *Isothermal line* is a curve showing the relations between pressure and volume in a fluid while a constant temperature is maintained. For a perfect gas the isothermal line is a rectangular hyperbola in accordance with Boyle's Law, then

$$p\,v = \text{a constant};$$

When the temperature is variable, then by Dalton's Law $p\,v = \mathrm{R}\,t$, R being a constant and $t$ the absolute temperature.

A practical expansion curve for non-superheated steam in a jacketed cylinder is the curve to equation

$$p\,v^{\frac{9}{10}} = \text{a constant};$$

but this will be vitiated by leakage if any occurs.

An *Adiabatic line* is a curve showing the relations between

pressure and volume in a fluid while the quantity of heat it contains is maintained constantly uniform; then

$$p\,v^{\gamma} = \text{a constant}.$$

$\gamma =$ for air $1\cdot4$, steam gas $1\cdot3$, saturated steam $1\cdot0646$.

### 390. Temperature of Boiling Water and Steam.

The temperature of boiling water varies with its density, purity, pressure and nature of containing vessel. The temperature of steam from the same or other water will always be uniform for a given pressure.

After water reaches temperature due to pressure, additional heat goes entirely to convert a portion of the water into steam.

### 391. Heat Required for Evaporation.

Supposing that a certain quantity of water is raised from 32° F. to 212° F. by 1000 units of heat, then it will require 5359 additional units to evaporate this quantity, which is given up again upon the condensation of the steam.

### 392. Solution and Evaporation of Steam.

1 oz. steam passed into 6·35 oz. water at 60° F. raises temperature to 212° F. Poured into shallow pan and allowed to cool to 60° F., the evaporation will reduce the water exactly to its original weight of 6·35 oz. This experiment has been held to show that the apparent increase in temperature of water upon application of heat is due to dissolved steam only. —*C. Wye Williams.*

### 393. First Law of Thermodynamics.

Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its

disappearance, mechanical energy in the proportion of 772 foot-lbs. for each British unit of heat. —*Rankine.*

When work is transformed into heat, or heat into work, the quantity of work is mechanically equivalent to the quantity of heat. —*Clerk Maxwell.*

Heat and work are mutually convertible, and Joule's equivalent is the rate of exchange. —*Jamieson.*

### 394. Second Law of Thermodynamics.

If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts, the effects of these parts in causing work to be performed are equal. —*Rankine.*

It is impossible, by the unaided action of natural processes, to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into another at a lower temperature.

—*Clerk Maxwell.*

It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature. —*Clausius.*

It is impossible by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects. —*Sir W. Thomson.*

Under existing conditions it is impossible to convert the whole of any given quantity of heat into work, and the proportion which can be converted into work follows a certain ratio determined by the absolute temperature of the source of heat and the lowest surrounding temperatures.

—'*Practical Engineer.*'

If an engine be such that, when it is worked backwards, the physical and mechanical agencies in every part of its motions are all reversed, it produces as much mechanical effect as can be produced by any thermodynamic engine, with the same temperature of source and refrigerator, from a given quantity of heat. —*Sir W. Thomson.*

### 395. Carnot's Law or Function (1824).

The ratio of the maximum mechanical effect to the whole heat expended in an expansive engine, is a function solely of the two temperatures at which the heat is respectively received and emitted, and is independent of the nature of the working substance.

### 396. Sir W. Thomson's Modification of Carnot's Law (1851).

The efficiency of a perfect heat engine is expressed by the ratio of the difference of the absolute temperatures of the source and condenser, to the absolute temperature of the source; absolute temperature being measured according to a scale so graduated that the temperature of a homogeneous body shall vary in simple proportion to the quantity of energy it possesses in the form of sensible or thermometric heat.

### 397. Law of Efficiency of Thermodynamic Engines.

The heat transformed into mechanical work is to the whole heat received as the range of temperature is to the absolute temperature at which it is received.

$$\frac{\tau_1 - \tau_2}{\tau_1} = \frac{T_1 - T_2}{T_1 + 461} \text{ (Fahr.)} = \frac{T_1 - T_2}{T_1 + 274} \text{ (Cent.)}.$$

*Example.*—What is the efficiency of a perfect steam engine working at an absolute initial pressure of 100 lbs. per sq. inch, corresponding to about 328° F., the temperature of the condenser being 104° F.?

$$\text{Efficiency} = \frac{328 - 104}{328 + 461} = \cdot 283.$$

Same example with the steam superheated to 600° F.

$$\text{Efficiency} = \frac{600 - 104}{328 + 461} = \cdot 45.$$

—*Hy. Dyer.*

### 398. Prof. Thomson's Formula for a Perfect Thermodynamic Engine.

S = temperature of source of heat in C.°
T = „ refrigerator in C.°
H = total heat, thermal units C.°, entering engine in a given time.
J = Joule's equivalent of 1390 foot-lbs. per 1° C.
W = work performed or power produced in foot-lbs.

$$W = J\,H\,\frac{S - T}{S + 274}.$$

### 399. General View of Heat Engine.

Heat supplied = work done + heat rejected.

$$\text{Efficiency} = \frac{\text{work done}}{\text{heat supplied}}.$$

### 400. Superheated Steam.

*Superheated*, *surcharged* (Hann and Gener), or *anhydrous* (Dr. Haycraft) steam or *stame* (Frost), is common steam heated away from contact with water. Theoretically it is more economical in use than common steam, as expansion takes place with less condensation, but, owing to its dryness and heat, the packing of the glands and the rods themselves are rapidly destroyed.

### 401. Condensation of Steam.

Steam may be condensed in

1. The vessel where its power is exerted . . . Savery, 1698. Newcomen, 1705.
2. A separate vessel. . . . Watt, 1769.

Steam may be condensed by

1. Projecting a cold fluid against the vessel containing it . } Savery.
2. Injecting a cold fluid amongst it Newcomen.
3. Exposing it to large surfaces of cold fluids or solids . } Watt. Cartwright.
4. The pressure of cold fluids against the vessel containing it . . } Perkins.
5. By the combination of two or more of these methods . . . } "

—*Tredgold.*

## 402. Velocity of Fluids flowing from Atmosphere into Vacuum.

$W$ = weight per cubic foot of the fluid in lbs.
$p$ = atmospheric pressure in lbs. per sq. foot.
$g$ = force of gravity = $32 \cdot 2$.
$v$ = velocity in feet per second.

$$v = \sqrt{\frac{2\,g\,p}{W}}.$$

Usually $p = 2116 \cdot 4$, then $2 \times 32 \cdot 2 \times 2116 \cdot 4 = 136{,}296 \cdot 16$, and approximately

$$v = \sqrt{\frac{136{,}300}{W}},$$

or for water $v = 46 \cdot 5$, and air $= 1338$.

In all cases allowance must be made for friction, say

$$\text{approx. } v = \sqrt{\frac{100{,}000}{W}}.$$

Velocity from one medium to another of given pressures P and $p$.

$$v = \sqrt{\frac{2\,g\,(P - p)}{W}}.$$

Steam of all pressures will rush into a perfect vacuum with a velocity of about 2000 feet per second, no allowance being made for friction.

Steam of 60 lbs. pressure will rush into atmosphere about 1800 feet per second.

### 403. Discharge of Steam through Pipes.

The velocity of discharge in pipes is in all cases proportional to the sectional area divided by the circumference; in round pipes this equals one-fourth of the diameter, thus:

$$\frac{d^2 \frac{\pi}{4}}{\pi d} = \frac{d}{4},$$

and quantity discharged therefore varies as the diameter$^3$.

The pressure lost in discharging a fixed volume of steam varies inversely as the 4th power of the diameter of the orifice.

The steam pipe for an engine must be calculated as if constantly passing steam of the maximum velocity required to supply any part of the stroke. With single cylinder engines maximum velocity may be taken as $1 \cdot 57$ times the mean velocity; and with double cylinder engine, cranks at right angles, maximum $= 1 \cdot 11$ times mean.

Single cylinder:

$$\begin{array}{l} \text{Max.} = \pi\, s\, \text{R}. \\ \text{Mean} = 2\, s\, \text{R}. \end{array} \quad \therefore \quad \text{Max. exceeds mean by } \frac{\pi}{2} = 1 \cdot 57.$$

—*Box.*

### 404. Diameter of Steam Pipes.

A = area of piston in sq. inches.

S = piston speed feet per minute.

$$\text{Area steam pipe sq. inches} = \frac{\text{A S}}{4800}.$$

Another rule (approximate):

$$\text{Diameter steam pipe in inches} = \sqrt{\frac{\text{I.H.P.}}{6}}.$$

### 405. Velocity of Steam in Pipes

100 feet per second.—*Unwin.*

| | | | |
|---|---|---|---|
| Through main steam pipe . . | 130 feet per second. | | |
| „ stop and throttle valves | 90 | „ | „ |
| „ steam ports . . . | 80 | „ | „ |

—'*Practical Engineer.*'

### 406. Thickness of Steam Pipes.

Cast-iron steam pressure pipes between 2 inches and 12 inches diameter, and up to 70 lbs. boiler pressure.

$$d + 4 = t \text{ in } \tfrac{1}{16}\text{ths of an inch.}$$

For exhaust steam, suction and ordinary low-pressure pipes of cast iron,

$$d + 10 = t \text{ in } \tfrac{1}{32}\text{nds of an inch.}$$

Large copper steam pipes (length = 5 diameters).

$d$ = inside diameter inches.
$t$ = thickness inches.
$p$ = working pressure (factor of safety 6).

$$\text{By experiment } t = \frac{p\,d}{4560}.$$

### 407. Expansion of Steam Pipes.

Steam pipes expand and contract about 1 inch in 50 feet, or ·02 inches per foot; hence the necessity for inserting expansion pipes between each rigid connection.

### 408. Loss of Heat by Pipes.

A 4-inch steam pipe covered in hair felt and canvas loses about 120 units of heat per foot run per hour at 60 lbs. per sq. inch pressure; bright copper pipe 350 units, rough black pipe 700 units. —*Box.*

### 409. Comparative Transmission of Heat.

1. Through various materials in mass.

| | |
|---|---|
| Poultry feathers | 6·2 |
| Hair felt | 11·4 |
| Cork powder | 13·6 |
| Sawdust | 14·2 |
| Plaster of Paris | 36·2 |
| Asbestos powder | 47·9 |
| Fossil meal | 52·1 |
| Fine sand | 56·3 |

2. Through various materials prepared as non-conducting coverings.

| | |
|---|---|
| Slag wool, hair and clay paste | 10·0 |
| Fossil meal and hair paste | 10·4 |
| Paper pulp alone | 14·7 |
| Asbestos fibre wrapped tightly | 17·9 |
| Fossil meal and asbestos powder | 26·3 |
| Coal ashes and clay paste, wrapped with straw | 29·9 |
| Clay, dung and vegetable fibre paste | 39·6 |
| Paper pulp, clay and vegetable fibre | 40·6 |

*Note.*—Other considerations, such as cost and durability, must receive attention in any practical application.

### 410. Non-conducting Dry Hair Felt.

| Maker's Number. | Approx. Weight per sheet 34″ × 20″. | Approx. Thickness uncompressed. |
|---|---|---|
| | oz. | inches |
| 0 | 12 | $\frac{3}{16}$ to $\frac{1}{4}$ |
| 1 | 16 | $\frac{1}{3}$ to $\frac{3}{8}$ |
| 2 | 24 | $\frac{1}{2}$ |
| 3 | 32 | $\frac{5}{8}$ to $\frac{2}{3}$ |
| 4 | 40 | $\frac{3}{4}$ to $\frac{5}{8}$ |
| 5 | 48 | 1 |

### 411. Comparative Radiation.

Approximate units of heat emitted per square foot per hour by pipes per 1° F. difference of temperature by radiation and air contact combined.

| | | |
|---|---|---|
| Dull tinned or galvanised surface . | ·62 + ·005 | Diff. in F.° |
| Black iron . . . . . . | ·9 + ·005 | „ |
| Rusted iron, wrought or cast . | 1·04 + ·005 | „ |

Or, say for any system of pipes 2 to 4 inches diameter 1·5 units, and for $\frac{3}{4}$-inch thin brass pipes 2·25 units, per 1° F. difference of temperature.

### 412. Heating by Steam.

When the external temperature is 10° F. below freezing point, in order to maintain a temperature of 60° F. there will be required with steam at 212° F.

(*a*) One square foot of pipe surface for each 6 square feet of window glass.

(*b*) One square foot of ditto for each 6 cubic feet per minute of air escaping for ventilation.

(*c*) One square foot of ditto for each 100 square feet of roof, wall, or ceiling.

(*d*) One square foot of ditto for each 80 cubic feet of space.

Approximately 1 cubic foot boiler space is sufficient for 2000 cubic feet space in rooms. Each foot-run of 4-inch pipe will heat 200 cubic feet air 1° F. per minute. Each H.P. of boiler will warm 40,000 cubic feet of space.

### 413. Heating by Hot Water.

Grate surface, 50 square inches per 100 feet run of 4-inch pipe.

Boiler surface exposed to fire, 2 square feet per 100 feet of 4-inch pipe.

Fuel required, $2\frac{1}{2}$ to 5 lbs. per hour per 100 feet run of 4-inch pipe.

For factories, 5 to 6 feet run of 4-inch pipe per 100 cubic feet.

For waiting-rooms, &c., 7 to 8 feet of 4-inch pipe per 100 cubic feet.

For greenhouses and hot-houses, required temperature F.° − 20 = feet run of 4-inch pipe per 100 cubic feet.

Pipes to be laid on rollers to allow for expansion and contraction, which equals $1\frac{1}{2}$ inches in 100 feet.

Air-cocks to be provided at highest points of pipe and wherever air is likely to lodge.

Stop-cocks may be half size of pipe, say 4-inch pipe = 2-inch cock.

Supply cistern = $\frac{1}{30}$ contents of boiler and pipes, and connected to return pipe.

Rust joint cement, 1 lb. sal-ammoniac, 1 lb. flour of sulphur, 1 cwt. cast-iron borings, made to a paste with water and caulked into sockets.

Special joints with india-rubber rings are now generally used for cast-iron hot-water pipes.

# SECTION X.

# STEAM BOILERS.

## 414. Varieties of Boilers.

*Early Forms.*—Spherical and cylindro-spherical, of cast iron, afterwards all wrought iron.

*Haystack or Balloon Boiler.*—Used formerly in Staffordshire: conical sides, dome top, small flat or hollow bottom.

*Wagon Boiler.*—Used formerly in Lancashire: flat ends, cylindrical top, hollow curved sides and bottom, held by stays.

*Egg-ended Boiler*—or cylindro-spherical, set horizontally, with "flash" flues, afterwards made with internal flue, furnace always external.

*Rastrick Boiler.*—Same as last, but set vertically, one or more horizontal flues leading to main flue through boiler.

*Cornish Boiler* (Trevithick).—Cylindrical, flat ended, with one flue tube containing furnace. London form shorter than original Cornish.

*Lancashire Boiler* (Fairbairn, 1844).—Similar to last, but with two flue tubes side by side containing furnaces.

*Breeches-flued Boiler.*—Similar to last, but with flue tubes uniting into one at back of bridges.

*Butterley Boiler.*—Similar to Cornish, but with flue tube enlarged at front end, and made elliptical to take wide furnace.

*Galloway Boiler*—of Cornish or Lancashire type, but with taper water tubes placed diagonally across flue tubes.

*French, or Elephant Boiler.*—Formed of three horizontal cylindrical parts connected to each other by necks, two of these (heaters or bouilleurs) surrounded by brick flues.

*Fairbairn Boiler.*—Same type as last, but with flue tube through each heater.

*Marine Boilers.*—Formerly made flat-sided, or any shape to fit ship, stayed where required. Now made cylindrical, short, large diameter, one, two, or three furnace tubes, combustion chamber at back end in one or more divisions. 50 to 250 small tubes from combustion chamber to smoke box at front end.

*Locomotive Boilers.*—Square furnace box at one end, water jacketed, connected with cylindrical boiler shell containing 200 to 300 small tubes for passage of gases to chimney.

*Field Boiler.*—Vertical cylindrical, with furnace contained in inner cylinder, top of latter below water line and holding suspended in flame 50 to 60 small double tubes for circulation of water.

*Babcock and Wilcox Boiler.*—Sectional water-tube boiler with inclined wrought-iron tubes expanded front and back into vertical sinuous headers which are connected by vertical tubes to cross-boxes on a horizontal steam and water drum. No stayed surfaces, and all joints metal to metal. All parts being of small diameter, the boiler is exceptionally safe from disastrous explosions.

### 415. Production of Steam in Cornish and Lancashire Boilers.

Approximately, 1 sq. foot of grate surface, 1 sq. yard of heating surface, 1 cubic yard of boiler space, will evaporate 1 cubic foot of water in 1 hour, producing 1 N.H.P., each cubic inch of water forming 1 cubic foot of steam at atmospheric pressure.

### 416. Horse-Power of Boilers.

*Nominal H.P. of Boiler* = cubic feet of water evaporated from 60° F. at any pressure in one hour = say 70,000 heat units.

*Heat H.P. of Boiler* is the amount of heat expressed in foot-lbs. transferred from the products of combustion into the water and steam per minute ÷ 33,000.

*Mechanical H.P. of Boiler* is the mechanical work done

per minute by the water as it evaporates and expands into steam $\div$ 33,000.

If P be absolute steam pressure in lbs. per sq. foot,

V = No. of cubic feet of steam produced per minute.

$$\text{Then } \frac{P\,V}{33{,}000} = \text{mechanical horse-power of boiler.}$$

In America a commonly accepted unit of horse-power for steam boilers is the evaporation of 30 lbs. water per hour from and at 212° F.

The actual horse-power developed by the steam from a boiler depends upon the engine in which it is utilised. In an average modern engine 1 cubic foot of water evaporated per hour will develop 4 horse-power.

### 417. Horse-Power of Boilers from Dimensions.

S = heating surface in sq. yards.

$g$ = grate surface in sq. feet.

$$\text{H.P.} = (S + g) \times \begin{cases} 1 \text{ for ordinary coal.} \\ \frac{3}{4} \text{ for good steam coal.} \\ \frac{1}{2} \text{ for best coal only.} \end{cases}$$

—*R. Armstrong.*

$a$ = area in sq. feet of water surface in boiler + horizontal sectional area of furnace tube in Cornish or Lancashire boiler.

| | H.P. = | | | |
|---|---|---|---|---|
| Plain cylindrical boiler . . . | $\frac{a}{6}$ | .. | .. | $\sqrt{S\,g}$ |
| Cornish or Lancashire boiler . . | $\frac{a}{6 \text{ to } 8}$ | .. | $\frac{3}{5}$ S | .. |
| Galloway boiler . . . . . . | $\frac{a}{4\cdot5}$ | .. | .. | .. |
| Multitubular boiler . . . . . | .. | $\frac{g}{\cdot5 \text{ to } \cdot8}$ | $\frac{1}{2}$ to $\frac{1}{3}$ S | $1\cdot8\sqrt{S\,g}$ |
| Marine boiler (I.H.P. = 5 N.H.P.) . | .. | .. | .. | $\cdot7\sqrt{S\,g}$ |

Another rule:—Nom. H.P. = $\frac{1}{6}$ length boiler in feet $\times$ diameter in feet.

The average number of cubic feet water evaporated per hour from cold feed with ordinary firing and good steam coal, is generally taken as the nominal horse-power of boiler, but two-thirds of a cubic foot is sufficient to develop 1 indicated horse-power in most steam engines.

### 418. Cost of Boiler Power.

Total cost of boiler power per horse-power per annum, including interest on capital, fuel, attendance and renewals, say 5*l.* 10*s.* for Lancashire and Cornish boilers, and 8*l.* for locomotive type.

### 419. Efficiency of Boilers.

The *Efficiency*, *Evaporative efficiency*, or *Economic efficiency* of a steam boiler is measured by the proportional quantity of the whole heat of combustion of a given fuel, which is absorbed into the boiler and applied to the conversion of water into steam, and is expressed by the weight of water evaporated from and at 212° F. by 1 lb. of the fuel.

The *Evaporative power* of a boiler is expressed by the total quantity of water evaporated per hour, or per square foot of grate area per hour, or per sq. foot or sq. yard of heating surface per hour. —*D. K. Clark.*

### 420. Space occupied by Coal.

Solid coal, say 40 cubic feet per ton.

Coal stores contain 45 cubic feet per ton.

Navy allowance for bunkers, 48 cubic feet per ton.

Coals will run down shoot at slope of 6 inches in 1 foot, or 26°; and down screen bars at 36°.

## 421. Calorific Value of Fuels.

Coals of lowest calorific capacity are those which burn with a long flame, their heat of combustion varying from 7840 to 8570 calories per kilogramme; after which come the gas coals, varying from 8400 to 8770 calories. The most advantageous coals appear to be generally the bituminous and semi-bituminous varieties, which show from 8570 to 8870 calories. Some anthracitous coals possess considerable calorific value, while the true anthracites approach, by their heat of combustion, the ordinary flaming coals, giving 8700 to 8100 calories. Petroleum gives 11,000 calories.

—*Mahler.*

Calories per kilog. $\times$ 1·8 = British heat units per lb. fuel.

## 422. Chemical Composition of Fuels.

| — | Coal (mean 97 kinds). | Coke. | Wood (ord. state). | Peat (ord. state). |
|---|---|---|---|---|
| Carbon . . . . | ·8040 | ·850 | ·408 | ·464 |
| Hydrogen . . . | ·0519 | .. | ·042 | ·048 |
| Oxygen . . . . | ·0787 | .. | ·334 | ·248 |
| Nitrogen and sulphur . | ·0246 | .. | .. | .. |
| Water . . . . | .. | .. | ·200 | ·200 |
| Ashes . . . . | ·0408 | ·150 | ·016 | ·040 |
| | Totals 1·0000 | | | |

## 423. Theoretical Units of Heat per Lb. of Fuel.

| | | A |
|---|---|---|
| Coal (mean of 97) . . . | 13,006 | 294 |
| Coke . . . . . . | 10,970 | 269 |
| Wood (dry) . . . . | 6,582 | 161 |
| ,, (ordinary) . . . | 5,265 | 129 |
| Charcoal . . . . . | 12,000 | 294 |
| Peat (dried) . . . . | 8,736 | 202 |

Column A gives cubic feet of air at 62° F. required per lb. of fuel. —*Box on 'Heat.'*

### 424. Absolute Heating Power of Fuel.

$p$ = absolute heating power of fuel in "calories."
C = percentage of carbon in fuel.
H = percentage of hydrogen in fuel.
W = „ of chemically combined or hygroscopic water.

$$p = 80 \cdot 8\,C + 296 \cdot 3\,H - 6 \cdot 4\,W.$$

—'*Industries.*'

The *Calorific Power* (Dr. Percy) of a substance is the number of units of heat produced by the combustion of a unit of weight of the substance.

### 425. Units of Heat per Lb. of Fuel (by Experiment).

| | | | |
|---|---|---|---|
| Hydrogen burning to water | | | 50,000 |
| Carbon | „ | carbonic oxide | 3,500 |
| „ | „ | carbonic acid | 14,000 |
| Carbonic oxide | „ | „ „ | 4,000 |
| Welsh coal | | | 8,500 |
| Newcastle coal | | | 8,000 |
| Lancashire coal | | | 7,500 |
| Derbyshire coal | | | 7,000 |
| Wood (ordinary state) | | | 5,000 |

### 426. Heating by Contact of Gases.

When difference of temperature is doubled, the rate of transmission is increased 2·35 times.

### 427. Rate of Transmission of Heat.

In locomotive boilers the rate of transmission per square foot of heating surface is 11 thermal units per hour per degree Fahrenheit of difference in temperature.

—*J. A. Longridge.*

In the boiler of s.s. *Meteor*, tested by Prof. Kennedy, 4769 thermal units per sq. foot heating surface per hour

were transmitted, or only 3 thermal units per hour per degree Fahrenheit of difference in temperature. —*D. Halpin.*

The average number of units of heat transmitted through boiler plates per sq. foot of surface per hour and per degree difference of temperature varies from 5 to 6 B.T.U. (British thermal units).

### 428. Condition of Boiler affecting Transmission of Heat.

Heat units absorbed per sq. foot per hour per degree Fahrenheit of difference in temperature.

| Condition of Boiler. | 1 sq. ft. Heating Surface per lb. Coal Burned per hour. | 4 sq. ft. Heating Surface per lb. Coal Burned per hour. |
|---|---|---|
| Very clean boiler . . . | 6·5 | 4·6 |
| Fairly „ „ . . . | 6·0 | 4·3 |
| Rather dirty „ . . . | 5·5 | 4·1 |

—*M. Longridge.*

### 429. Loss of Strength in Copper Plates when Heated.

At boiling point, 60 lbs. pressure, 307·5° F. = 10 per cent.
At 500° F. . . . . . . . . . 50 „
At faint red heat, 1000° F. . . . . . 75 „
At dull red heat, 1300° F. . . . . 100 „

### 430. Loss of Strength in Iron Plates when Heated.

At boiling point, 60 lbs. pressure, 307·5° F. = *nil.*
If anything, the strength increases up to 320° F.
At about 550° F. decrease begins to be perceptible.
At faint red heat, say 1000° F. . . 25 per cent.
At dull red heat, say 1300° F. . . 50 „

### 431. Comparative Value of Heating Surfaces.

Area of shell exposed to flame . . = 1
Horizontal area above flame . . . = 1
Surface inclined towards flame . . = $\frac{3}{4}$
Vertical surface . . . . . . = $\frac{1}{2}$
Surface inclined from flame . . . = 0
Horizontal surface below flame . . = 0
Internal cylindrical flues = $\frac{1}{2}$ circumference.
Small tubes . . = $\frac{2}{3}$ „
Shell of Cornish or Lancashire boiler = $\frac{2}{3}$ to $\frac{3}{4}$ of lower half.

### 432. Heating Surface of Boilers.

| Class. | Proportion of Heating Surface to Grate Surface. | Heating Surface to evaporate 1 cubic foot per hour. |
|---|---|---|
| Plain cylindrical . . . | 10–16 to 1 | 18 sq. feet. |
| Cornish and Lancashire . . | 15–25 to 1 | 14 „ |
| Multitubular . . . . | 30–40 to 1 | 9 „ |
| Locomotive . . . . . | 60–80 to 1 | 6 „ |
| Vertical . . . . . | .. | 10–16 „ |

In portable boilers tried by Bramwell for the Royal Agricultural Society, with a heating surface varying from 16 to 37 sq. feet per cubic foot evaporated per hour, the total heat effect varied from ·651 to ·776, and the temperature of escaping gases from 775° F. to 500° F. He recommended in the ordinary way 12 to 15 sq. feet heating surface per cubic foot evaporated per hour, and a grate surface of $\frac{1}{24}$ to $\frac{1}{30}$ of this.

Babcock and Wilcox water-tube boiler, $11\frac{1}{2}$ sq. feet heating surface to each N.H.P.

A Lancashire boiler will evaporate 5 lbs. water per sq. foot total heating surface per hour, or 2 cubic feet per sq. foot fire-grate surface per hour, without pushing.

### 433. Products of Combustion.

100 lbs. coal:
- 80 lbs. carbon ..... → $293\frac{1}{3}$ lbs. carbonic acid gas, say 2520 cub. ft.
- 5 lbs hydrogen ..... → 45 lbs. water, say 946 cub. ft. steam.
- 15 lbs. sundry ..... → 15 lbs. ash.

960 lbs. air:
- $746\frac{2}{3}$ lbs. nitrogen ..... → $886\frac{2}{3}$ lbs. nitrogen, say 12,000 cub. ft.
- $213\frac{1}{3}$ lbs. oxygen ...

180 lbs. air:
- 140 lbs. nitrogen .....
- 40 lbs. oxygen ......

These figures assume perfect combustion and no losses.

### 434. Air Required to Burn Fuel.

For the complete combustion of 1 lb. of fuel, the lbs. air theoretically necessary = ·117 times the percentage of carbon + ·35 times the percentage of free hydrogen.

e. g. carbon, 70 per cent.; hydrogen, 3 per cent.

$\cdot 117 \times 70 + \cdot 35 \times 3 = 9\cdot 24$ lbs. air per lb. fuel.

—'*Industries.*'

Good Lancashire coal requires theoretically 10 lbs. weight of air per lb. of coal for perfect combustion, but should be allowed 15 to 16 lbs. in practice. —*M. Longridge.*

Practically, we may say, 13 cubic feet of air at 60° F., 30″ bar., weigh 1 lb., and 12 lbs. air are required to combine with constituents of 1 lb. coal for perfect combustion, but to allow for working conditions, 24 lbs. is necessary; or 312 cubic feet = 700,000 cubic feet of air per ton of coal.

100 cubic inches atmospheric air at 60° F. and 30″ bar. = 31 grains; ∴ 1 cubic foot = ·093 lbs.; 12 cubic feet oxygen weigh 1 lb., and to obtain 1 lb. oxygen, 5 lbs. air must pass through fire = 60 cubic feet.

2 to 3 lbs. oxygen required to burn 1 lb. of coal, or, assuming only two-thirds effective, 180 to 270 cubic feet will be required.

In general, the quantity of air provided should be double the minimum theoretical quantity.

Air and smoke together equal about 2000 cubic feet per cubic foot of water evaporated, temperature say 800° F.

Maximum economical draught for boilers = pressure due to ½ inch head of water, causing consumption of 36 lbs. coal per hour per sq. foot fire-grate, and requiring 24 lbs. air per lb. coal.

Air spaces in fire door = 3 sq. inches per sq. foot of fire-grate.

### 435. Heat in Flue.

With Cornish boiler, temperature of escaping gases at base of flue may be as low as 500° F.

With short multitubular boiler, as high as 1200° F.

A pyrometer indicating up to 1000° F. was placed in the flue at end of a multitubular boiler of locomotive type, containing tubes 7 feet × 2¾ inches, when the pointer went beyond the range of the instrument = say 1100° F.

The temperature is generally ascertained by hanging strips of metal foil, on an iron wire, across the flue, and noting which are melted by the heat, viz.: copper 2000°, aluminium 1800°, zinc 750°, lead 630°, tin 440°.

Temperature of boiler furnace, say 2400° F.

### 436. Brick Chimney-Shafts.

The bond usually adopted is one course of headers to four of stretchers.

Up to 120 feet high the top length is generally one brick thick; above that height, top length 1½ brick thick.

Height of any length of uniform section should not exceed 30 feet, and should be less in thin sections.

45 feet is an ordinary total height for two steam boilers, but in some towns, as Manchester and Leeds, the minimum height allowed is 90 feet.

A minimum wind pressure of 55 lbs. per sq. foot must be allowed for in calculating stability.

Round chimneys should not exceed 25 times internal diameter in height.

## 437. Force of Wind.

Miles per hour $\times$ 88 = feet per minute.

" $\times \frac{22}{15} =$ " second.

$$p = \frac{v^2 \text{ ft. per sec.}}{500}.$$ —*Hutton.*

$p = \cdot 144$ velocity miles per hour. —*Crosby.*

$p$ = pressure in lbs. per sq. foot against a plane surface normal to direction of wind.

$a$ = area of maximum section in sq. feet perpendicular to direction of wind.

$\theta$ = angle of exposed surface with plane of section.

$c$ = coefficient according to shape of surface presented.

P = total resistance of surface in direction of wind.

$$P = c \,.\, a \,.\, p.$$

Coefficients, $c$ =

| | |
|---|---|
| Disc or rectangular plane . . | $= 1$ |
| Cylinder . . . . . . | $= \frac{\pi}{4}$ |
| Sphere . . . . . . | $= \frac{\pi}{8}$ |
| Wedge . . . . . . | $= \sin\theta$ |
| Cone or pyramid . . . | $= \frac{\sin\theta}{2}$ |

A square chimney presents the same resistance either square or diagonally placed.

A roof may be taken as equal to a wedge whose base is twice the rise of roof; $\sin\theta$ would then be measured from vertical.

An inclined plane of area $a$ will at small angles present a resistance approximately varying as $\sin^2\theta\, a\, p$, and at large angles as $\sin\theta\, a\, p$. A formula agreeing closely with Hutton's experiments is

$$P = a\, p \sin\theta^{1\cdot 84 \cos\theta},$$

$a$ being full area of surface.

In Hutton's experiments $a = 32$ sq. inches.

### 438. Size of Factory Chimney for Boilers.

$W$ = weight of coal burnt in lbs. per hour.
$A$ = area of chimney in sq. feet at top.
$H$ = height of chimney in feet.
$c$ = cubic feet evaporated per hour.

$$A = \frac{W}{14\sqrt{H}}, \qquad W = 14\,A\sqrt{H}, \qquad H = \left(\frac{W}{14\,A}\right)^2$$

or,

$$A = \frac{1\cdot 5\, c}{\sqrt{H}}.$$

| | | |
|---|---|---|
| Chimney for single boiler, area | | $= \frac{1}{8}$ fire-grate. |
| Do. under 150 feet high for more than one | " | $= \frac{1}{10}$ " |
| Do. over 150 feet high do. | " | $= \frac{1}{15}$ " |

$$\text{Area of chimney in sq. inches} = \frac{\text{lbs. coal per hour} \times 12}{\sqrt{\text{height feet}}}.$$

—*Bourne.*

Area of chimney usually $\frac{1}{10}$ area of fire-grate and 40 feet high. —*Scott Russell.*

20 square inches area per N.H.P. of engine.
Height of about 20 times internal diameter.
Flues $\frac{1}{5}$ area of fire-grate, diminishing to $\frac{1}{10}$ at chimney.

Height of chimney = 45 feet.

Area of chimney $= \dfrac{\text{area fire-grate}}{\sqrt{\text{height}} \times 1\cdot58}$. —*Elswick.*

Do. $= 1\frac{1}{2}$ sq. ins. per lb. of coal per hour. —*Murray.*

Area chimney sq. ins. $= \dfrac{120 \times \text{grate surface sq. ft.}}{\sqrt{\text{height feet}}}$.

—*J. T. Henthorn.*

Area sq. feet $= \dfrac{\frac{3}{10}\text{ boiler H.P.} + 10}{\sqrt{\text{height feet}}}$. —*Berg.*

Boiler horse-power of chimney $= 3\frac{1}{3}$ (area sq. feet $- 0\cdot6$ $\sqrt{\text{area}}$) $\sqrt{\text{height feet}}$. —*W. Kent.*

Effective area of chimney = 2 inches less all round than actual area.

Approximate horse-power of round chimney $= \dfrac{d \text{ inches}^3}{300}$.

Funnel for marine engine = 3 to 5 sq. inches per indicated horse-power.

### 439. Velocity of Gases in Chimney.

Velocity of gases $= 8\sqrt{\text{motive height}} = 8\sqrt{h\left(\dfrac{T - t}{459 + T}\right)}$.

Do. practically $= 6\sqrt{\dfrac{h}{1 + \dfrac{T - t}{500}}}$. —*Tredgold.*

Ordinary velocity of gases in chimney shaft $= 2\cdot4\sqrt{H}$.

Most economical temperature of escaping gases = 600° Fahr.

At this temperature the volume of air entering furnace is doubled on exit.

A cubic foot of water requires 10 lbs. coal to evaporate it; 10 lbs. coal require 210 lbs. air for complete combustion, = say 2750 cubic feet.

The force of the draught in a chimney stack is the deficiency of weight of the column of rarefied air in the chimney compared with a similar column of the external air.

A factory chimney erected by Boulton and Watt, 80 feet high, 400 sq. inches area, coal consumption 300 lbs. per hour, had a suction in chimney = 1 inch of water.

### 440. London County Council Rules for Furnace Chimney Shafts.

The width of a shaft at the base, if square on plan, must be at least one-tenth, and if circular on plan at least one-twelfth of the total height.

A shaft must have a batter of 2½ inches in every 10 feet of height.

The brickwork must be at least 8½ inches thick at the top of the shaft and for 20 feet below, and must be increased 4½ inches in thickness for every 20 feet of additional height, measured downwards.

No portion of the enclosures of a shaft is permitted to be constructed of fire-brick, and any fire-brick lining to be used must be in addition to the thickness of, and independent of, the brickwork.

No cornice or other projection is allowed to project more than the thickness of the brickwork at the top of the shaft.

### 441. Rate of Combustion.

In lbs. of coal burnt per sq. foot of fire-grate per hour.

| | |
|---|---|
| Cornish boilers | 3½ |
| Old land boilers | 10 |
| Recent land boilers | 13–14 |
| Modern marine boilers | 16–24 |
| Locomotive boilers | 80–120 |

Another account:—

| | lbs. |
|---|---|
| Cornish boilers for pumping engines . . | 4–10 |
| ,, and others for factory uses. | 10–15 |
| Marine boilers, ordinary rates . . . | 15–20 |
| Boilers with strong chimney draught . | 20–30 |
| Locomotives . . . . . . . | 60–120 |

A boiler may be made to do 70 per cent. more work if the consumption of fuel can be doubled, but the life of the boiler will be considerably shortened.

### 442. Boiler Furnaces.

With bituminous fuel the layer in the furnace should be about 4 to 6 inches thick, and should never exceed 12 inches. Thin firing is more economical, but requires more careful stoking. Fresh fuel should be put in front of the fire and the red-hot fuel pushed back, or should be spread thinly over the surface after the hollows are filled up. With coke or hard coal the fire may be thicker, especially if a blast be used. For locomotive boilers the fire may be 18 inches thick.

For land boilers with hand firing, fuel should be added about every half hour, and more air admitted for the next ten minutes.

Small coal, or slack, has about half the evaporative power of coal or coke.

### 443. Heat in Boiler Furnaces.

1. Temperature of furnace, say about 2500° F.
2. ,, escaping gases, say 600° to 1200° F.
3. ,, steam and water in boiler, say 300° F.
4. ,, water in condenser, say 100° F.

Difference between (1) and (2) is absorbed by the water in raising its temperature, by the steam as latent heat, and

by the air entering furnace in excess of quantity required for combustion.

Difference between (2) and (3) is utilised in creating draught; 600° is the most economical temperature of escaping gases, as it allows sufficient difference of temperature for rapid passage of heat to water, and the density is sufficiently reduced to give rapid ascending current in chimney shaft.

Difference between (3) and (4) is utilised in the engine.

The difference of temperature or quantity of sensible heat does not by itself represent the comparative efficiency.

### 444. Loss of Heat in Boilers.

Assuming that it requires 10 lbs. of coal to evaporate 1 cubic foot of water from 60° into steam at 60 lbs. per square inch gauge pressure, the loss of heat may be shown, as follows, to be nearly 50 per cent. :—

| | |
|---|---|
| Total heat of combustion in 1 lb. of coal in British thermal units = say 13,000. 13,000 units per lb. × 10 lbs. coal . . = | 130,000 |
| Steam at 60 lbs. pressure has a total heat of 1207 units. 1207 − 60° temperature of feed-water = 1147 units per lb. of water. 1 cub. ft. water = 62·5 lbs. 62·5 × 1147 = | 71,687 |
| Loss in chimney, 24 lbs. air, required to burn 1 lb. coal. 24 × 10 = 240 lbs. to burn 10 lbs. coal. Specific heat of air = ·2374. Temperature of escaping gases = 600°. 240 × ·2374 × 600 . . . . . = | 34,185 |
| Loss in hot ashes, fuel dropped through, &c., say 7 per cent. of total heat . . . = | 9,100 |
| Loss by radiation and conduction, say 7 per cent . . . . . . . . = | 9,100 |
| Loss by imperfect combustion, say $4\frac{1}{2}$ per cent. = | 5,850 |
| | 129,922 |

In ordinary cases large boilers utilise about 8000 units of heat per lb. of coal.

### 445. Duty of Engines.

"Duty" dates from Lean's 'Reporter,' published in 1811.

$s$ = standard of comparison in lbs. =

| | |
|---|---|
| Cwt. any coal . . . | 112 lbs. |
| Bushel Welsh coal . . | 94 „ |
| „ Newcastle coal . | 84 „ |

$w$ = lbs. weight coal burnt per I.H.P. per hour.

$n$ = No. of cwts. or bushels burnt per hour.

$$\text{Duty in ft.-lbs. per standard} = \frac{\text{I.H.P.} \times 33{,}000 \times 60}{n}.$$

$$\text{,,} \qquad \text{,,} \qquad = \frac{33{,}000 \times 60 \times s}{w}.$$

$$\text{Duty in million ft.-lbs. per cwt.} = \frac{221 \cdot 76}{w}.$$

Cornish duty (prior to 1855):

$g$ = gallons of water pumped per hour.

$f$ = feet lift of water pumped.

$n$ = bushels of 94 lbs. coal.

$$\text{Duty} = \frac{10\,g\,f}{n}.$$

Since 1855 Cornish duty has been reckoned upon the cwt. of 112 lbs.

### 446. Progress in Duty of Engines.

| A.D. | | | |
|---|---|---|---|
| 1700 | Savery . . . | 5 | million ft.-lbs. per 100 lbs. fuel |
| 1770 | Newcomen . . | 12 | „ „ „ |
| 1780 | Watt . . . . | 27 | „ „ „ |
| 1830 | Cornish engine . | 87 | „ „ „ |
| 1890 | Multiple cylinder . | 120 | „ „ „ |

But even in the last case less than one-eighth of the theoretical value of the fuel is obtained.

—*Prof. Thurston.*

### 447. Duty of Engines Compared with Coal Used.

C = consumption of coal per I.H.P. in lbs.

D = duty in million lbs. raised 1 foot high by 1 cwt. of coals.

| C. | D. | C. | D. |
|---|---|---|---|
| 1 | 221·760 | 5 | 44·352 |
| 1·5 | 147·840 | 6 | 36·960 |
| 2 | 110·880 | 7 | 31·680 |
| 2·5 | 88·704 | 8 | 27·720 |
| 3 | 73·920 | 9 | 24·640 |
| 4 | 55·440 | 10 | 22·176 |

### 448. Modern Duty.

The duty of a steam engine alone is measured by the amount of steam used per hour per I.H.P.

The duty of an engine and boiler combined is measured by the coal consumed per hour per I.H.P.

The E.H.P. or Brake H.P. ought, however, to be taken in preference to the I.H.P.

### 449. Evaporative Value at Different Temperatures.

In stating the evaporative power of a boiler, it is usual to express it in terms of feed-water evaporated from 212°.

$t$ = actual temperature of feed-water.
T = total heat of steam under given pressure.
$c$ = cubic feet of water evaporated from $t$°.
C = „ „ „ from 212° by same quantity of heat.
T − $t$ = heat imparted.

$$C = c\,\frac{T - t}{966\cdot 1}.$$

## 450. Hand-Firing and Mechanical Stoking.

Summary of trials of Vicars' mechanical stokers at the City of London Electric Lighting Station, Bankside, S.E., against hand-firing.

| — | Babcock and Wilcox Boilers. | |
|---|---|---|
| | Hand-Firing. | Vicars' Patent System. |
| Date of trial | 26th April, 1894 | 4th June, 1894 |
| Duration of trial | 9 hours | 6 hours |
| Description of fuel used | Nixon's Navigation | Bituminous rough, small |
| Price of fuel used | 16*s.* per ton | 10*s.* per ton |
| Fuel consumed | 13,664 lbs. | 9184 lbs. |
| Ashes and clinker | 532 lbs. | 1022 lbs. |
| Weight of combustible | 13,132 lbs. | 8162 lbs. |
| Per cent. of ash | 3·9 per cent. | 11·1 per cent. |
| Draught in flue (av.) | ·48″ water | ·55″ water |
| Temperature in flue (av.) | 210·8° C. | 453° F. |
| Water evaporated | 118,535 lbs. | 82,100 lbs. |
| Temperature of feed water | 54·3° Fahr. | 62° F. |
| Average steam pressure | 145·9 lbs. | 157·5 lbs. |
| Water evaporated per hour | 13,170 lbs. | 13,683 lbs. |
| Water evaporated per lb. of fuel under actual conditions | 8·67 lbs. | 8·94 lbs. |
| Water evaporated per lb. of combustible | 9·02 lbs. | 10·05 lbs. |
| Water evaporated per lb. of fuel from and at 212° F. | 10·50 lbs. | 10·78 lbs. |
| Water evaporated per lb. of combustible from and at 212° F. | 10·93 lbs. | 12·12 lbs. |
| Cost of evaporating 500 gallons | 40·8*d.* | 24·8*d.* |

### 451. Experiments on Evaporation in Boilers.

| Class. | Size. | Lbs. Water per lb. Coal. | Lbs. Coal per cubic foot Water. |
|---|---|---|---|
| Cornish . . | 20 H.P. | 6·764 | 9·212 |
| Lancashire . | 25 „ | 7·547 | 8·256 |
| Galloway . . | 35 „ | 9·5 | 6·579 |
| Field . . . | .. | 10·9 | 5·734 |

In a case where an engine was allowed to get into bad condition, with considerable leakage past valves and pistons, it appeared as if 3 lbs. of water were evaporated by 1 lb. of coal, or 21 lbs. of coal were required to evaporate 1 cubic foot of water. This was on the assumption that the engine required only the normal amount of steam.

### 452. Effect of Supervision of Boilers.

Men being aware the work was measured: 100 hours, evaporation (average from and at 212° F.) = 9·7 lbs. water per lb. fuel.

Men not being aware the work was measured: 220 hours, evaporation (average from and at 220° F.) = 9·3 lbs. water per lb. fuel.

Difference = 4½ per cent. in favour of supervision.

—*E. Bennis.*

### 453. Consumption of Steam in Engines.

| | | |
|---|---|---|
| Non-condensing . | . | 30 lbs. steam per I.H.P. per hour. |
| Compound condensing | | 20 „ „ „ |
| Triple compound | . | 15 „ „ „ |

### 454. Feed-Water required for Boilers.

Gallons feed-water required per hour = say nom. H.P. of boiler × 10 to allow for losses, or I.H.P. of engine × 5 for ordinary work, or × 6 for maximum work.

Boilers supplying engines pumping water against accumulator pressure and working intermittently require about $2\frac{1}{2}$ gallons per working hour per effective H.P. on the average of the year.

### 455. Advantage of Heating Feed-Water.

1 lb. water requires 160 units of heat to raise it from 52° F. to 212° F., and 1000 units of heat to evaporate it from and at 212° F. If, therefore, the feed-water be raised to 212° F. by means of exhaust steam, the 160 units will be saved, and the resulting economy will be

$$\frac{160 \times 100}{1000 + 160} = 13 \cdot 8 \text{ per cent. gain.}$$

Or, putting it another way, the percentage of gain at any pressure by increasing the temperature of feed-water may be found by the following formula:

H = total heat of steam at boiler pressure.
T = temperature of feed after heating.
$t$ = „ „ before „

$$\text{Gain per cent.} = \frac{100\,(T - t)}{H - t}.$$

*Example*;—A boiler working at 100 lbs. pressure is supplied with water at 100° F. from a condensing engine. When passed through a Green's economiser, the temperature of the feed is raised to 250° F. What is the gain per cent.?

$$H = 1216 \cdot 5. \qquad T = 250. \qquad t = 100.$$

Then

$$\frac{100\,(T - t)}{H - t} = \frac{100\,(250 - 100)}{1216 \cdot 5 - 100} = 13 \cdot 4 \text{ per cent. gain.}$$

### 456. Fuel Economisers.

Those by Green and Son, Limited, of Manchester and Wakefield, are best known. They act by heating the feed-water and removing lime, and consist of a series of 4-inch cast-iron pipes, about 9 feet long, in four or more rows, placed vertically in main flue and connected by top and bottom boxes. The feed-water passes through these on its way to the boiler, and the products of combustion pass on the outside in the opposite direction. An economiser receiving the gases at 650° F., and reducing their temperature to 350° F., may raise the feed-water from 100° F. to 250° or 300° F., and produce an economy of from 10 to 15 per cent. in the fuel consumption. The number of economiser pipes per boiler is four pipes per ton of coal consumed per week, or say, one pipe to every 3 I.H.P.

### 457. Consumption of Fuel.

The consumption of coal per I.H.P. depends upon the boiler as well as the engine, say

| | | | | |
|---|---|---|---|---|
| Non-condensing engine | 3 | lbs. coal | per I.H.P. | per hour. |
| Simple condensing ,, | 2 | | ,, | ,, |
| Compound ,, ,, | 1·75 | | ,, | ,, |
| Triple compound ,, | 1·5 | | ,, | ,, |
| Quadruple ,, ,, | 1·25 | | ,, | ,, |

### 458. Possible Economy in Coal Consumption.

Total units heat (B.T.U.) in 1 lb. coal say 12,000, representing 12,000 × 772 foot-lbs. = 9,264,000 foot-lbs., or if all utilised a consumption of $\frac{33,000 \times 60}{9,264,000} = \cdot 213$ lbs. coal per H.P. per hour, while the average consumption is actually about ten times that amount. But ·213 lbs. is less than a perfect engine would consume owing to the unavoidable loss

in the condenser, e.g. let 1 lb. coal supply steam without any loss, at 300 lbs. pressure = 417° F., the condenser being 100° F., then $\frac{417 - 100}{417 + 460} = \cdot 36$ which is the ratio of the available units to the total units of heat, and $\frac{\cdot 213}{\cdot 36} = \cdot 6$ lbs. coal per H.P. per hour as the maximum possible efficiency with a perfect engine under the conditions stated, or from $\frac{1}{3}$ to $\frac{1}{4}$ of what is now usually obtained.

### 459. H.P. per Ton Weight.

Maximum I.H.P. of engines per ton of boiler weight, including fittings, mountings and water.

| | |
|---|---|
| Torpedo boats, Thorneycroft boiler . . | 77·8 |
| Locomotive engines . . . . . . | 55·4 |
| Small high-pressure marine . . . | 12·0 |
| Do. compound „ . . . . . | 16·0 |
| Do. triple compound „ . . . . | 20·0 |

In Maxim's flying machine the total weight of engines and boiler complete = 8 lbs. per E.H.P. = 280 H.P. per ton.

### 460. To Calculate Size of Boiler.

Say Cornish boiler for high-pressure engine:

$d$ = diameter of cylinder in feet.
$s$ = stroke in feet.
R = revolutions per minute.
$r$ = ratio of cut-off.
$p$ = boiler pressure, lbs. per sq. inch by gauge.
$n$ = number of cylinders.
S = cubic feet steam required per hour, allowing 25 per cent. for contingencies.

$$S = 1\cdot 25\, d^2 \frac{\pi}{4} s\, r\, 2\, n\, R\, 60 = \text{say } 120\, d^2 s\, r\, n\, R.$$

$v$ = relative volume of steam at $p$ pressure.

W = weight of water to be evaporated in lbs. per hour.

$$W = \frac{62 \cdot 5\, S}{v}.$$

$c$ = combustion of coal in lbs. per sq. foot fire-grate per hour, say for Cornish boiler = 12 lbs.

$e$ = evaporation in lbs. of water from 60° F. per lb. of coal, say for Cornish boiler = 7 lbs.

$c \times e$ = lbs. water evaporated per sq. foot fire-grate per hour.

A = area of fire-grate in sq. feet.

$$A = \frac{W}{c\,e}.$$

$l$ = length of fire-grate in feet, say $4 \cdot 5$ to $5 \cdot 5$, but must not exceed twice the width.

$w$ = width of fire-grate in feet.

$$w = \frac{A}{l} + \cdot 166.$$

D = diameter of boiler shell = $1 \cdot 75\, w$.

L = length of „ = 4 D.

When $w$ exceeds $3 \cdot 25$, make two Cornish boilers or one Lancashire.

For latter, D = $2\frac{1}{2}\, w$ ($w$ being width of *one* furnace).

## 461. Cornish Boiler.

Approximate heating surface in sq. yards of unit value,

$$= \frac{L \frac{\pi}{2} (d + \frac{2}{3} D)}{9} - \text{space occupied by seatings.}$$

$$= \text{say} \cdot 17\, L\, (d + \tfrac{2}{3} D).$$

Total capacity in cubic feet

$$= L \frac{\pi}{4} (D^2 - d^2) = \cdot 8\, L\, (D^2 - d^2).$$

Approximate space for steam, remainder water,

$$= \frac{L\,D^2\,\frac{\pi}{4}}{6} = \cdot 13\,L\,D^2.$$

Minimum steam space = quantity required for 10 revolutions of engine. Water space 5 to 10 cubic feet per N.H.P., and 5 feet super. water surface per N.H.P.

### 462. Comparison of Cornish Boiler with I.H.P. of Engine.

I.H.P. of engine = effective heating surface of boiler in sq. yards of unit value.

$\frac{1}{2}$ I.H.P. of engine = cubic yards total capacity of boiler, of which $\frac{1}{4}$ = steam, $\frac{3}{4}$ = water.

$\frac{2}{3}$ I.H.P. of engine = area of fire-grate in sq. feet.

Steam receiver may be attached to boiler, maximum size equal in diameter to flue tube, length = twice diameter.

Steam dome to allow supply pipe to take dry steam, may equal $\frac{2}{3}$ diameter of flue tube, with height = diameter of flue.

### 463. Proportions of Boilers.

Cornish boilers (one flue).

| N.H.P. | Length. | Diam. | Furnace. | | Flue Diam. |
|---|---|---|---|---|---|
| | | | Diam. | Length. | |
| | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. |
| 15 | 16 6 | 4 9 | 2 9 | 4 0 | 2 9 |
| 20 | 21 6 | 5 0 | 3 0 | 5 0 | 2 6 |
| 30 | 26 0 | 5 9 | 3 3 | 6 6 | 2 6 |

Lancashire boilers (2 flues).

| | | | | | |
|---|---|---|---|---|---|
| | ft. | ft. in. | ft. in. | ft. in. | ft. in. |
| 20 | 20 | 6 0 | 2 0 | 4 0 | 1 9 |
| 25 | 25 | 6 0 | 2 0 | 4 6 | 1 9 |
| 30 | 28 | 6 6 | 2 3 | 5 0 | 2 0 |
| 35 | 30 | 7 0 | 2 6 | 5 6 | 2 3 |

For more than 35 H.P. two or more boilers are required.

### 464. Lancashire Boilers.

Goodeve's proportions:—

$d$ = diameter of one tube. Shell = $2\frac{1}{2}\,d$. Space between tubes = $\cdot 15\,d$. Space between tubes and shell = $\cdot 12\,d$. Width bottom flue = $1\frac{1}{4}\,d$.

### 465. Fire-Bars.

Ordinary furnaces should not exceed 6 feet in length for Welsh coal, the bars being in two lengths; for Newcastle or other flaming coal, say 4 feet 6 inches long, with bars in one length. Dead-plate should be 9 to 15 inches wide. Fire-bars say 3 feet long, 3 inches deep in middle, $\frac{3}{4}$ inch thick at top, tapered to $\frac{3}{8}$ inch thick at bottom; bevelled one end to rest on dead-plate, to allow for expansion, and notched at other to rest on wrought-iron bearer: if notched both ends, there should be not less than 1 inch play. Chipping faces or distance pieces on bars should be made at both ends and middle. Air spaces between bars $\frac{3}{8}$ inch to $\frac{5}{8}$ inch, usually $\frac{1}{2}$ inch. The fire-grate should incline downwards towards the back, $\frac{3}{4}$ inch to 1 inch per foot. Passage above bridge = one-sixth area of grate. Perforations in furnace door, $\frac{3}{8}$ inch to $\frac{1}{2}$ inch diameter; total area, from 2 to 5 sq. inches per sq. foot fire-grate.

### 466. Boiler Seatings.

With old form of wheel draught the boiler was set on a mid-feather: this is a bad arrangement. Should be set on fireclay blocks forming side walls, the resting surfaces not wider than one-twentieth diameter of boiler, or $\frac{3}{4}$ inch per foot diameter.

Flues should be large enough for a man to pass entirely

round, area should be kept as uniform as possible, corners rounded, and angles filled up.

Plain cylindrical boilers should be hung by wrought-iron brackets at intervals, riveted on, and supported on stone but not bolted down, and should be set with flash flues, i.e. the gases pass directly from furnace, over the bridge, and along bottom of boiler, to chimney. Boilers should be set with a fall of about 1 in 200, or $\frac{1}{16}$ inch per foot, towards front.

### 467. Size of Manholes in Boilers.

| | | | |
|---|---|---|---|
| 12 × 8 | inch can | be entered by | small boy. |
| 13 × 9 | ,, | ,, | lad. |
| 14 × 10 | ,, | ,, | average man. |
| 15 × 12 | ,, | ,, | stout man. |

### 468. Boiler Tubes.

| Class of Boiler. | Ratio, Length to Diameter. | Ratio, Tube Area to Grate Area. |
|---|---|---|
| Multitubular boilers, with chimney draught . . . . . . . | 24 to 1 | 1 to 7 |
| Locomotive boilers . . . . . | 120 to 1 | 1 to 4 |
| Small marine boilers, with high pressure engines . . . . . . | 33 to 1 | 1 to 6 |
| Large marine boilers, with condensing engines . . . . . . . | 20 to 1 | 1 to 3 |

1 sq. foot of fire-box is equal to 3 sq. feet tube surface; $\frac{1}{2}$ diameter should be left between the tubes for circulation and escape of steam.

Heating surface of small tubes = $\frac{2}{3}$ of circumference, of furnace tubes = $\frac{1}{2}$ circumference.

In multitubular boilers the stay-tubes should be spaced so as to support the whole plate, irrespective of support from other tubes.

## 469. Water-Gauge Glass.

Lowest sight-level of water-gauge glass should be 3 to 4 inches above furnace crown or highest point of boiler exposed to flame.

Water heated from its point of maximum density (39° F.) to boiling-point (212° F.) expands about one twenty-third of its volume.

## 470. Taper of Plugs for Boiler-Cocks.

For pressures up to 30 lbs. per sq. inch, a taper of 1 in 8 on each side is found to work well; but for pressures of about 100 lbs., a taper of 1 in 12 is necessary to insure tightness; say 1 in 10 minimum for pressure of 60 lbs.

## 471. Blow and Scum.

The sediment in a boiler, and the floating impurities, should be blown out after a short period of rest, say during meal times.

When laying off for cleaning, the water should not be all blown out, or the scale will harden excessively and be more difficult to remove.

## 472. Blowing-off to prevent Incrustation.

A 20 H.P. boiler working at a pressure of 70 lbs. per sq. inch (316° F.) will blow off 120 cubic feet of water in a day of 12 hours. To replace the water thus blown off, 120 cubic feet of cold water at 60° have to be introduced; and to bring it to 316°, 1,904,640 heat units, otherwise 272 lbs. of coal, are required. The remedy for this is to soften and heat the feed-water before its introduction to the boiler.

## 473. Boiler Scale.

Increased quantity of fuel required to evaporate water:—

| | | | |
|---|---|---|---|
| Scale $\frac{1}{16}$ | inch thick | = | 15 per cent. |
| " $\frac{1}{4}$ | " | = | 60 " |
| " $\frac{1}{2}$ | " | = | 150 " |

—*Prof. J. G. Rogers.*

Order of deposition of impurities as water becomes concentrated:—

1. Carbonate of lime.
2. Sulphate of lime.
3. Salts of iron, as bases or oxides, and some of these of magnesia.
4. The silica or alumina, usually with more or less of organic matter.
5. Common salt. —*M. Cousté.*

Soda (carbonate) is the best natural de-incrustant.

## 474. Hardness of Water.

When a water contains in solution one part by weight of lime, or other equivalent hardening salt, in 100,000 parts of water, it is said to possess 1° of hardness.

Water of less than 6° of hardness softens lead to an extent dangerous to health if used for domestic purposes.

Parts carbonate lime per 100,000 water $\times \frac{7}{10}$ = grains per imperial gallon, or degrees of hardness on Clark's scale. Carbonate of lime produces temporary hardness in water, sulphate of lime produces permanent hardness.

Water is said to be hard when it contains more than 7 grains of dissolved mineral matter per gallon. The water of London holds about 16 grains, that of Kent 24 grains. All well waters are more or less hard.

### 475. Incrustation in Boilers.

If water contains 20 grains of mineral impurities per gallon, $\frac{1}{2}$ cwt. of scale is precipitated and left by the water boiled away in a week of 60 hours, at the rate of 350 gallons evaporated per hour. If allowed to accumulate, this gives a coating of $\frac{3}{16}$ inch in 3 months over 250 sq. feet of plate.

If the feed-water contains 30 grains of solid matter per gallon, a 20 H.P. boiler will deposit half a pound per hour.

### 476. Sea-Water.

| | | Parts per 1000. |
|---|---|---|
| Proportion of salt in water of | open sea | 32 to 38 |
| " " | Red Sea | 43 |
| " " | Mediterranean | 38 |
| " " | British Channel | 35·5 |
| " " | Arctic Ocean | 28·5 |
| " " | Black Sea | 21 |
| " " | Baltic | 6·6 |

—*Ure.*

Average specific gravity of sea-water at 60° F., pure distilled water being 1 :—

| | | | |
|---|---|---|---|
| Faraday | 1·027 | Marcett | 1·0277 |
| Mallett | 1·0278 | Fitzroy | 1·027 |

Salts contained in sea-water :—

| | Parts per 1000. |
|---|---|
| Chloride of sodium | 25 |
| Muriate of magnesia | 3 |
| Sulphate of magnesia | 2 |
| Sulphate of lime | 1 |
| Others | 1 |
| Total | 32 |

—*Faraday.*

Weight of 1 cubic foot about 64·14 lbs.

### 477. Boilers Fed with Salt Water.

$E$ = evaporation in cubic feet per hour.
$D$ = density allowed in boiler, normal sea-water being 1·000.
$d$ = density of feed-water.
$C$ = cubic feet of brine to be blown out per hour.

$$C = \frac{E\,d}{D - d}.$$

To find D when $\frac{1}{3}$ feed blown off:

$$\frac{1}{3} = \frac{\frac{2}{3}\,d}{D - d}. \qquad \therefore \quad D = 3\,d.$$

### 478. Causes of Priming.

Changes in density of feed-water, as fresh to salt, or *vice versâ.*

Rapid extraction of steam after perfect rest; sometimes sudden starting of engines.

Feeding with muddy water, or water contaminated with sewage.

Steam-space too limited.

Defective circulation in boiler.

Hard firing.

### 479. Corrosion of Boilers.

When rivet heads between high and low water line are attacked, the corrosion has been reduced in land boilers by painting the inside of boiler between those levels with a mixture of "drippings from shafts, boiled oil and blacklead" every time the boilers are cleaned out. This was adopted at Woolwich Arsenal.

### 480. Grease in Boiler,

when carried over with the steam, is very detrimental to life and efficiency of boiler. The thin coating of grease deposited only during a ship's trial trips has been found to reduce the efficiency of the tubes as heating surfaces from 8 to 15 per cent., the mean result of many experiments being 11 per cent.

481. Safety Valves for Boilers

should always be in duplicate.

Area in sq. inches for each = ·004 to ·006 area of fire-grate surface, usually ·025 sq. inches per sq. foot heating surface, or ·5 sq. inches per sq. foot grate surface, irrespective of working pressure.

Actual lift of valve $= \frac{2d}{p}$ or $\frac{d}{36}$, but freedom must be allowed for a lift of $\frac{1}{4}d$. The lift required is less for large valves and heavy pressures than for small valves and light pressures.

Valves should be flat faced to prevent sticking, face $\frac{1}{8}$ inch to $\frac{1}{12}$ inch wide.

In estimating the blow-off pressure, add $\frac{1}{16}$ inch to the actual diameter inside face of seat.

When diameter would exceed 4 inches, two or more valves must be provided.

A = effective area of heating surface, sq. feet.
H = boiler H.P. (1 cub. ft. per hour evap. from 60°).
G = grate surface, sq. feet.

$$A = 8(H + 2{\cdot}5\sqrt{H}), \qquad G = \frac{H + 2{\cdot}5\sqrt{H}}{2}, \qquad G = \frac{A}{16}.$$

$$\text{Diam. of safety valve, ins.} = \sqrt{\frac{A}{27}}.$$

—*Box.*

$$\text{Diam. of safety valve, ins.} = \sqrt{\frac{\text{grate surface, sq. ft.}}{\text{gauge pressure, lbs.}}}.$$

—*Tredgold.*

Twin safety valves, each—

$$\text{Area} = 18\,\frac{\text{grate surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}};$$

$$\text{or area} = \frac{0{\cdot}6 \text{ heating surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}}.$$

Or one as above fitted as an easing valve, and one as follows loaded to 1 lb. per sq. inch less—

$$\text{Area} = 4\,\frac{\text{grate surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}} + \text{area of guides of valve};$$

$$\text{or area} = \frac{0\cdot133 \text{ heating surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}} + \text{ditto}.$$

If the heating surface exceeds 30 sq. feet per square foot of fire-grate, safety valve must be determined from heating surface. —*Inst. Eng. Scot.*

Heating surface in sq. feet $\div$ 25 = area valve disc sq. inches. —*U.S. Board of Supervisors.*

$\cdot005 \times$ lbs. water evaporated per hour = area valve disc sq. inches.

—*Committee of U.S. Board of Supervising Inspectors.*

Area sq. inches = $\frac{4}{5}$ grate area sq. feet. —*Molesworth.*

Orifice of safety valve (flat faced) = circf. $\times$ lift.

" " (mitred) = circf. $\times$ lift $\div 1\cdot414$.

—*Somerscales.*

$a$ = effective area of opening.
$d$ = diameter, $l$ = lift.
Flat-faced, $a = l\,d\,\pi$.
Mitred, $a = 2\frac{1}{4}\,l\,d + 1\frac{1}{8}\,l$.

## 482. Board of Trade Rules for Safety Valves.

| Boiler Pressure. | Area per sq. ft. of Fire-Grate. | Boiler Pressure. | Area per sq. ft. of Fire-Grate. |
|---|---|---|---|
| 15 | 1·25 | 70 | ·441 |
| 30 | ·833 | 80 | ·394 |
| 40 | ·681 | 90 | ·357 |
| 50 | ·576 | 100 | ·326 |
| 60 | ·500 | 120 | ·277 |

### 483. To Calculate Safety-Valve Leverage.

$a$ = area of valve in sq. inches.
$p$ = gauge pressure in lbs. per sq. inch.
$W$ = weight on end of lever in lbs.
$w$ = weight of lever in lbs.
$w'$ = weight of valve and stud in lbs.
$L$ = distance between weight and fulcrum in inches.
$g$ = ,, centre of gravity of lever and do.
$l$ = ,, valve centre and do.

$$W = \left[pa - \left(w' + \frac{wg}{l}\right)\right]\frac{l}{L}. \qquad L = \left[pa - \left(w' + \frac{wg}{l}\right)\right]\frac{l}{W}.$$

$$p = \frac{\frac{wg + WL}{l} + w'}{a}. \qquad a = \frac{\frac{wg + WL}{l} + w'}{p}.$$

The lever safety valve was invented by Papin.

### 484. Notes on Spiral Springs.

Effective number of coils = generally two less than apparent number, owing to flattening at ends for bases.

Stroke = effective number of coils × compression or extension of each coil.

Minimum pitch of spiral = diameter of steel in inches + twice compression of one coil under full load, but coils may lie close when spring is for tension only.

Diameter of coil = say 8 times diameter of steel.

Working load may stretch each coil = $\frac{1}{2}$ diameter of steel composing spring.

To increase stroke, add to the number of coils.

Spring in tension is more accurate for exact work than one in compression.

Best form of section is circular, but square form is stronger, as 10 to 7.

Two or more springs may be used, one within the other.

## 485. Spiral Springs.

Formula for strength and deflection.

E = Compression or extension of one coil in inches.
D = Diameter of coil in inches from centre to centre.
$d$ = Diameter or side of square of steel composing spring in $\frac{1}{16}$ths of an inch.
W = Weight applied in lbs.
$c$ = a constant found by experiment, which may be taken as 22 for round steel and 30 for square steel.

$$E = \frac{D^3 W}{d^4 c}.$$

## 486. Spiral Springs, Rankine's Formula.

$d$ = diameter of wire in inches.
$c$ = coefficient of transverse elasticity of wire, say 10,500,000 to 12,000,000 for charcoal iron wire and steel.
$r$ = radius to centre of wire in coil.
$n$ = effective number of coils.
$f$ = greatest safe shearing stress, say 30,000.
W = any load not exceeding greatest safe load.
$v$ = corresponding extension or compression.
W′ = greatest safe steady load.
$v'$ = greatest safe steady extension or compression.

$$\frac{W}{2} = \text{greatest safe sudden load.}$$

$$\frac{W}{v} = \frac{c\,d^4}{64\,n\,r^3}. \qquad W' = \frac{\cdot 196\,f\,d^3}{r}. \qquad v' = \frac{12\cdot 566\,n\,f\,r^2}{c\,d}.$$

Ratio $\frac{W}{v}$ should be ascertained by direct experiment.

—*Rankine's 'Machinery and Millwork.'*

In two series of experiments analysed by the author, the ratio W to $v$ was greater by 12 and 30 per cent. respectively than given by the formula, the former in tension, the latter in compression.

### 487. Spiral Springs for Safety Valves.

$a$ = area of valve in sq. inches.
$c$ = 11,000 for square steel = 8000 for round steel.
D = diameter of spring, inches centre to centre of coil.
E = compression or extension of one coil, inches.
$p$ = pressure lbs. per sq. inch on valve.
$d$ = diameter of steel or side of square in inches.
$d_1$ = " " " in sixteenths.

$$d = \sqrt[3]{\frac{a\,p\,D}{c}}.$$

Let

$$E = \frac{D^3\,a\,p}{30\,d_1^{\,4}} \text{ for square steel;}$$

then

$$E = \frac{D^3\,a\,p}{22 \cdot 8\,d_1^{\,4}} \text{ for round steel.}$$

—'*Practical Engineer.*'

### 488. Initial Compression of Springs for Safety Valves

may be 40 times the lift of the valve, and assuming the lift of all sizes to be $\frac{1}{10}$ inch, the initial compression will then be 4 inches.

Or may be 1·11 diameter of valve in inches.

Or, by another rule:

$$\text{Initial compression} = \frac{80 \times d \text{ of valve ins.}}{p \text{ lbs. sq. in.}}.$$

If lever is used, then movement of lever must be taken in calculating spring, instead of lift of valve.

### 489. Spring-Balance Safety Valves.

The levers are generally proportioned so that 1 lb. pressure per sq. inch on the valve gives 1 lb. pull on the spring, but the spring is tightened up to the blowing-off pressure, so that the actual indication is only shown when the blowing-off pressure is exceeded. The length of lever from centre of valve to fulcrum is made equal to diameter of valve, and the length from fulcrum to centre of attachment of spring is made equal to the diameter of valve multiplied by its area, all inches. The total length may be increased if the same proportion of its subdivisions be retained.

### 490. To Calculate Springs for Safety Valves.

Given boiler pressure and grate surface, find—

1. Diameter of valve.
2. Load required.
3. Lift of valve.
4. Initial compression of spring.
5. Assume diameter of coils.
6. Find diameter of steel.
7. Compression of each coil.
8. Effective number of coils.
9. Pitch of spiral.
10. Effective length of spring.
11. Total length.

### 491. Factor of Safety, Steam Boilers.

Test pressure = $\frac{1}{3}$ ultimate strength.

Working pressure, if under periodical inspection, = $\frac{1}{5}$ do.

Working pressure, if not under independent inspection, = $\frac{1}{6}$ do.

In estimating ultimate strength, ample allowance to be made for defects in design or workmanship.

### 492. Testing Boilers.

*Government Yards.*—New boilers to be tested by hydraulic pressure to three times their working pressure. Boilers in use not to be worked more than 300 hours without being laid off for examination. To be tested periodically to twice their working pressure.

*Best Private Practice.*—New boilers to be tested to twice their working pressure. Boilers in use not to be worked more than 1000 hours without being laid off for examination. To be tested after repairs to $1\frac{1}{2}$ times their working pressure. If working with impure water, to be examined after 500 hours.

*Locomotive Boilers.*—Usually tested by hydraulic pressure to not more than 10 per cent. above working pressure, say 160 lbs. working pressure = 175 lbs. test pressure.

### 493. Riveting for Boilers.

In iron :—

Ring seams to be single riveted, longitudinal seams double riveted.

For equal area of plate and rivet, the linear pitch in single riveted joints and diagonal pitch in double riveted joints should be

$$= \frac{\text{sectional area of one rivet}}{\text{thickness of plate}} + \text{diameter of rivet.}$$

For same conditions, the linear pitch in double riveted joints should be

$$= \frac{2 \text{ sectional area of one rivet}}{\text{thickness of plate}} + \text{diameter of rivet,}$$

but is generally made about one-sixth less than this, to avoid straining in caulking. Double riveting should always be zigzag.

For rivets in double shear, take 1·75 times above areas.

Fairbairn estimated strength of solid plate at 50,000 lbs.

per sq. inch, double riveted joint as worth 70 per cent., and single riveted joint 56 per cent. He recommended double riveted longitudinal joints $2\frac{1}{2}$ inches linear pitch, 2 inches diagonal pitch [say for $\frac{3}{4}$ inch rivets and $\frac{3}{8}$ inch plates].

### 494. Small Screwed Stays or Water-Space Stays.

$p$ = working pressure in lbs. per sq. inch.
$P$ = pitch of stays in inches.
$a$ = net sectional area of stay.
$s$ = safe stress in lbs. per sq. inch = 4000 copper, 5000 wrought iron, 6000 steel.

$$a = \frac{P^2 p}{s}, \quad P = \sqrt{\frac{s\,a}{p}}, \quad p = \frac{a\,s}{P^2},$$

say 4 to $4\frac{1}{2}$ inches pitch for locomotive work, 6 to 8 inches for marine work. Diameter $\frac{3}{4}$ to 1 inch, generally double the thickness of plates.

### 495. Long Stay Bolts

should be strong enough to support the area assigned to them, with a factor of safety of $\frac{1}{6}$, assuming no support from the thickness of plate.

### 496. Strength of Flat Plates supported by Stays (Lloyd's Rules).

$p$ = working pressure lbs. per sq. inch.
$P$ = greatest pitch of stays in inches.
$t$ = thickness of plate in sixteenths of an inch.
$c$ = constant =

90 for plates up to $\frac{7}{16}$ inch thick held by screw stays with riveted heads.

100 for plates above $\frac{7}{16}$ inch do. do.

110 for plates up to $\frac{7}{16}$ inch thick held by screw stays and nuts.

120 for plates above $\frac{7}{16}$ inch do. do.
140 for plates held by plain stays with double nuts.
160 for do. do. and washers at least half thickness of plates and diameter of $\frac{2}{5}$ pitch, riveted to the plates.

In the case of front plates of boilers in steam space and exposed to direct action of heat, reduce these numbers by 20 per cent.

$$p = \frac{c\,t^2}{P^2}.$$

### 497. Strength of Flat Plates.

$t$ = thickness in inches.
$r$ = radius „ if circular.
$l$ = length „ if rectangular.
$b$ = breadth „ „
$p$ = pressure in lbs. per sq. inch.
$f$ = maximum stress on material per sq. inch.
$a$ = distance centre to centre of stays in inches.
$s$ = side of square plate in inches.

Circular plate supported at edge,

$$f = \frac{5}{6} \cdot \frac{r^2}{t^2} \cdot p.$$

Circular plate encastré,

$$f = \frac{2}{3} \cdot \frac{r^2}{t^2} \cdot p.$$

Square plate stayed,

$$f = \frac{2}{9} \cdot \frac{a^2}{t^2} \cdot p.$$

Square plate encastré,

$$f = \frac{1}{4} \cdot \frac{s^2}{t^2} \cdot p.$$

Rectangular plate encastré,

$$f = \frac{1}{2} \cdot \frac{l^4\,b^2}{l^4 + b^4\,t^2} \cdot p.$$

—*Unwin.*

## 498. Strength of Flat Encastré Circular Wrought-Iron Plates.

$p$ = working pressure lbs. per sq. inch.
$P$ = test ,, ,,
P = ultimate ,, ,,
P = bulging ,, ,, to elastic limit.
$t$ = thickness in inches.
T = ,, in sixteenths of an inch.
$d$ = diameter of plate in inches.
$r$ = radius ,, ,,
$f$ = maximum stress on material in lbs. per sq. inch.

$$p = \frac{440\,(T + 1)^2}{d^2 - 12}.$$ —*Pract. Eng. Pocket-Book.*

$$P = 60{,}000\,\frac{t^2}{r^2} \text{ (safe load} = \tfrac{1}{2} \text{ test pressure).}$$

—*H. Cherry.*

$$P = 1000\,\frac{t}{d} \text{ (12 tons elastic strength per sq. inch of material; } \tfrac{1}{3} = \text{safe load).}$$ —*D. K. Clark.*

$$P = \frac{f\,3\,t^2}{2\,r^2} \;(f = 44{,}800 \text{ lbs.; } \tfrac{1}{4}\,P = \text{safe load}).$$

—*Unwin.*

$$P = \frac{f\,t^2}{r^2} \text{ (safe load } \tfrac{1}{4}\text{).}$$

—*Rankine.*

## 499. Ultimate Strength of Boiler-Shell.

Longitudinal strength:

$$p\,d\,l = 2\,t\,l\,c \quad \therefore \quad p\,d = 2\,t\,c,$$

$$p = \frac{2\,t\,c}{d}, \qquad t = \frac{p\,d}{2\,c}.$$

Transverse strength:

$$p \frac{d^2 \pi}{4} = \pi (t + d) t c,$$

divide by $\pi d$, then

$$p \frac{d}{4} = \left(\frac{t}{d} + 1\right) t c;$$

but $\frac{t}{d}$ will rarely exceed $\cdot 01$, and may therefore be omitted.

$$\therefore \quad p \frac{d}{4} = t c, \qquad p = \frac{4 t c}{d}, \qquad t = \frac{p d}{4 c},$$

or the transverse strength is double the longitudinal.

### 500. Helical Joints for Boilers.

Ratio of strength to longitudinal joint

$$= \frac{2}{\sqrt{(3 \cos^2 \phi + 1)}},$$

$\phi$ = angle of inclination from longitudinal direction.

### 501. Collapsing Pressure of Boiler Tubes.

Length not exceeding 15 diameters.
*Cylindrical:*

$$p = 33 \cdot 61 \times \frac{(100\, k)^{2 \cdot 19}}{\mathrm{L}\, d};$$

—*Fairbairn*

or

$$\log p = 1 \cdot 5265 + 2 \cdot 19 \log 100\, k - \log \mathrm{L}\, d;$$

or, approximately,

$$p = \frac{800{,}000\, t^2}{\mathrm{L}\, d}.$$

*Elliptical:*

$$p = \frac{800{,}000\, t^2}{\mathrm{L}\,(2\, r)}, \qquad r = \text{radius of flatter curve},$$

$$p = \frac{800{,}000\, t^2}{\mathrm{L}} \times \frac{2\, \mathrm{D}^2}{d}.$$

D $d$ are the two diameters in inches, L the length in feet.

### 502. Boilers.—Comparison between Bursting and Collapsing Pressures.

P = internal or bursting pressure in lbs. per square inch.
$p$ = external or collapsing „ „
$c$ = ultimate strength of single riveted joint = say 30,000 lbs.
$l$ = length of unsupported cylindrical tube in feet.
D = diameter of boiler in inches.
$d$ = „ tube „
T = thickness of shell plate in inches.
$t$ = „ tube plate „
R = ratio of tube diameter to shell diameter $= \frac{d}{\mathrm{D}}$.

$$\mathrm{P} = \frac{2\,\mathrm{T}\,c}{\mathrm{D}} = \frac{60{,}000\,\mathrm{T}}{\mathrm{D}}.$$

$$p = \frac{800{,}000\, t^2}{l\, d}.$$

$$\frac{\mathrm{P}}{p} = \frac{60{,}000\,\mathrm{T}\, l\, d}{800{,}000\, t^2\,\mathrm{D}} = \frac{\mathrm{T}\, l\,\mathrm{R}}{13 \cdot 3\, t^2}.$$

$$\therefore \quad \text{When } \mathrm{P} = p, \text{ then } l = \frac{13 \cdot 3\, t^2}{\mathrm{R\,T}}.$$

### 503. Collapsing Pressures of Flues.

| L′ × D″ | $\frac{1}{4}''$ | $\frac{5}{16}''$ | $\frac{3}{8}''$ | $\frac{7}{16}''$ | $\frac{1}{2}''$ | |
|---|---|---|---|---|---|---|
| 400 | 97 | 158 | 235 | 329 | 441 | lbs. per sq. in. |
| 500 | 77 | 126 | 188 | 263 | 353 | „ |
| 600 | 65 | 105 | 157 | 219 | 294 | „ |
| 700 | 55 | 90 | 134 | 188 | 252 | „ |
| 800 | 48 | 79 | 117 | 164 | 229 | „ |
| 900 | 43 | 70 | 104 | 146 | 196 | „ |
| 1000 | 38 | 63 | 94 | 131 | 176 | „ |

—*Munro.*

Length 7 diameters or over.

$t$ = thickness in sixteenths of an inch.

D = diameter in feet.

$$p = \frac{16\,t^2}{D^2}.$$

Where length is less than 7 diameters the strength is inversely as the length, or the collapsing pressure

$$= p\frac{7\,D}{L}.$$

—*W. I. Ellis.*

### 504. Fox's Corrugated Flues.

$t$ = thickness in inches.

D = mean diameter inches.

$p$ = working pressure in lbs. per sq. inch.

$$p = \frac{14,000\,t}{D}.$$

—*Board of Trade.*

$t$ = thickness in sixteenths.

D = maximum diameter inches.

$$p = \frac{1234\,(t-2)}{D}.$$

—*Lloyd's Registry.*

### 505. Locomotive Boiler.

Pressure 130 to 150 lbs. per sq. inch.

Feet of heating surface = inches diameter piston$^2$ × 4.

Heating surface of firebox = $\frac{1}{12}$ to $\frac{1}{10}$ of total.

Sq. feet area fire-grate = inches diameter piston − 1.

Tubes 10 to 12 feet long, $1\frac{5}{8}$ inch to $1\frac{3}{4}$ inch internal diameter, 11 to 13 W.G., $\frac{5}{8}$ inch clearance between.

Shell plates $\frac{3}{8}$ inch to $\frac{5}{8}$ inch, $t = \frac{p\,d}{960}$ when $t$ = thickness sixteenths, $p$ = pressure lbs. sq. inch, $d$ = diameter inches.

Diameter of shell = diameter piston $\times$ 3.

Smoke-box tube plate = $1\frac{1}{2}\ t$.

Side plates, outer casing, fire-box = $t + \frac{1}{16}$ inch.

Throat plate and back plate = $t + \frac{1}{8}$ inch.

Firedoor = 18 inches $\times$ 12 inches. Inner casing of fire-box, copper.

Inner tube plate, upper part = $\frac{1}{4}$ inch thicker than lower part.

Holes in tube plates = $\frac{1}{8}$ inch smaller at fire-box end and $\frac{1}{8}$ larger at smoke-box end than mean outside diameter of tubes.

Stay bolts, 4 inch pitch, $\frac{3}{4}$ inch over thread with $\frac{3}{8}$ inch plate, $\frac{7}{8}$ inch with $\frac{1}{2}$ inch plate, $\frac{15}{16}$ inch with $\frac{5}{8}$ inch plate.

Girder stays (8) in two plates 5 inches $\times\ \frac{5}{8}$ inch to 6 inches $\times\ \frac{3}{4}$ inch, 2 inches clearance above crown, secured by stay bolts same size as in sides of fire-box.

Steam dome = $\frac{1}{2}$ diameter of barrel, height = diameter, thickness same as shell plates, top $\frac{3}{4}$ inch to $\frac{7}{8}$ inch thick, and $7\frac{1}{2}$ inches high.

Manholes, 16 inches diameter.

Twin safety valves, each with clear passage of area = $\frac{1}{12000}$ of heating surface $\therefore$ diameter in inches = $\cdot 08\ \sqrt{\text{heating surface, sq. feet}}$. Conical seats, bearing $\frac{1}{16}$ inch wide.

Chimney, 13 feet 3 inches from rail level to top, smallest diameter in inches = $4\ \sqrt{\text{grate area, sq. feet}}$.

Steam pipe = $\frac{1}{16}$ area of piston.

Air space through bars = $\frac{1}{5}$ of grate area.

Fire-bars, centre depth = $\frac{1}{8}$ length; thickness, top = $\frac{1}{50}$ length; thickness, bottom = $\frac{1}{100}$ length; end depth = $\frac{3}{5}$ middle depth.

—'*Railway Press.*'

# SECTION XI.

# THE STEAM ENGINE.

## 506. Early Engines.

*Savery's Engine.*—A receiver was filled with steam from a boiler, the communication closed and water applied externally; condensation allowed water to rise through a bottom clack; steam again admitted above drove the water up to a higher level through an upper clack.

*Newcomen's Engine.*—Open-topped cylinder had a loosely fitting piston attached by rod and chain to one end of a beam, the beam pivoted at its centre and attached by chain to pump rods at other end. Steam admitted under piston at atmospheric pressure allowing weight of pump rods to lift piston and force water up from the pump. Jet of water admitted into the cylinder then caused condensation, and pressure of atmosphere forced piston down while lifting pump rods.

*Watt's First Engine* was a Newcomen engine with the cylinder closed on top and steam admitted instead of air, and with a separate condenser. In the old atmospheric engine increased power required increased diameter and stroke of piston; in Watt's engine increased power was obtainable by increasing the steam pressure only.

The general proportions of beam engines were:—Depth of beam = diameter of cylinder. Stroke of piston = twice diameter. Length of beam = three times the stroke. Area of beam flanges at centre = 3 sq. inches per 2000 lbs. on piston. Indoor stroke when piston going into cylinder, outdoor stroke reverse.

### 507. Economy of High-Pressure Steam.

The pressure of steam increases in a greater ratio than its density, whence it follows that the higher the pressure to which the steam is raised, the less *proportionate* quantity of water it contains, and therefore the less fuel is consumed, since a given quantity of fuel will evaporate nearly the same weight of water at all temperatures. —*Pole.*

The expenditure of heat, to produce a given weight of steam at a pressure of 10 atmospheres, is only 4 per cent. more than that required at a pressure of 1 atmosphere.

Doubling the pressure in the boiler, with one-third more coal, doubles the power obtained from the engine. Thus the power obtained is greater in proportion than the extra amount of coal used to increase the pressure of steam in the boiler.

### 508. Advantage of Expanding Steam.

When steam is cut off at $\frac{2}{3}$ of the stroke, the power of an engine is only diminished by 7 per cent., while the consumption of steam is diminished by 33 per cent. Cut off at half stroke the power is reduced 16 per cent., and the consumption of steam 50 per cent.

### 509. Economy of Compound Engines.

The economy of compound engines consists mainly in the higher pressure of steam employed permitting greater expansion, and in the subdivision of the work over two or more cylinders, limiting the range of temperature in each, and therefore the loss from condensation.

### 510. Progress of Compound Engines.

1781. Hornblower patented the use of two cylinders where the steam first operated in one and then by expansion

in the other also, and applied them to a single-acting pumping engine.

1782. Watt patented cutting off steam before end of stroke, but had previously adopted it.

1804. Woolf patented small and large cylinders of same stroke, pistons moving in same direction and parallel. Steam used first in small cylinder, then in large. Applied to double-acting engines with separate condenser.

1805. Earle patented the use of large and small cylinders superposed, with two pistons mounted on the same rod.

1820. Aitken and Steel built engines with three cylinders, two small and one large.

1834. Wolff patented a compound engine with two cylinders and intermediate reservoir to regulate the pressures. Also the conversion of simple engines to compound by the addition of a high or low-pressure cylinder to a low or high-pressure engine.

1839. Whitman patented the trunk piston, the steam first acting in the annular space of the cylinder, then expanding into the other end.

1841. Sims patented Earle's arrangment, with the exception that the bottom of the smaller piston was in constant communication with the top of the larger and with the condenser.

1842. Zander patented the use of a small cylinder to receive the steam, passing after slight expansion into two larger cylinders all connected with same crank shaft. The low-pressure cylinders were steam jacketed.

1844. Smith patented high and low-pressure oscillating cylinders working same crank. Perkins adopted very high pressures.

1845. McNaught patented addition of a high-pressure cylinder between the main centre and crank of beam engine.

1854. First successful application of compound cylinders to marine engines by Randolph, Elder & Co.

### 511. Horse-Power.

*Actual* H.P = 33,000 foot-lbs. per minute in all calculations, but the actual work of a horse is about 22,000 foot-lbs. per minute. One H.P of 33,000 foot-lbs. per minute = approximately, 15 foot-tons per minute.

### 512. Nominal Horse-Power.

*Watt's nominal* H.P. for low-pressure engine (pressure 7 lbs. per sq. inch* above atmosphere)

$$= \text{area sq. inches} \times 7 \times 128 \times \sqrt[3]{\text{stroke feet}} \div 33{,}000$$
$$= d \text{ in inches}^2 \times \sqrt{\text{stroke feet}} \div 47.$$

*Boulton and Watt's* N.H.P. for high-pressure engines,

$$= d^2 \div 14 \ (\therefore 11 \text{ sq. in. piston per N.H.P.})$$

Do. do. for condensing engines,

$$= d^2 \div 28 \ (\therefore 22 \text{ sq. inches piston per N.H.P.})$$

*Bourne's* N.H.P. three times that of Watt, viz. for a pressure of 21 lbs. above atmosphere.

*Royal Agricultural Society's* old rule was 10 circular inches of piston area and 50 lbs. pressure represent a nominal horse-power.

At the present time N.H.P. is a useless commercial term, generally depending upon size of cylinder, and irrespective of pressure or speed.

Sometimes N.H.P. for non-condensing engines was $d^2 \times \sqrt[3]{\text{stroke feet}} \div 20$; for simple condensing engines $d^2 \div 30$; and for compound engines $(D^2 + d^2) \div 33$ or 30.

* In all machinery actuated by fluid pressure, the square inch, which is the standard unit, introduces a needless complication. James Watt lost a good opportunity in not establishing the circular inch as the standard.

Circ. inches × ·7854 = sq. inches.

Sq. inches × 1·27324 = circ. inches.

*Admiralty* N.H.P. was formerly used in classifying the power of marine engines,

$= \text{area sq. in.} \times \text{speed ft. per min.} \times 7 \div 33{,}000.$
$= d \text{ in.} \times \text{speed ft. per min.} \div 6000.$
= about one-sixth of the indicated H.P.

*Seaton's estimated* H.P.

$= D^2 \text{ l.p. cylr.} \times \sqrt{p} \times \text{revns. per min.} \times \text{stroke ft.} \div 8500.$

*Lloyd's Committee* N.H.P. (1872)

$$= \tfrac{1}{2}\left(\frac{D^2 \times \text{stroke ft.}}{630} + F\right),$$

where F = total width fire-grate inches.

*N.E.C. Inst. Eng. and Shp.* (1877) *Normal* I.H.P.

$= \text{for screw engines } \tfrac{1}{100}\,(D^2 \times \sqrt[3]{\text{stroke ft.}} + 3\,B)\,\sqrt[3]{p}.$
$= \text{for paddle engines } \tfrac{1}{160}\,(D^2 \times \sqrt[3]{\text{stroke ft.}} + 5\,B)\,\sqrt[3]{p}.$

where B = the heating surface of the boilers in sq. ft., and if there are two low press. cylrs. $D^2$ = sum of sqs. of diams.

## 513. Indicated Horse-Power.

*Indicated* H.P. = mean $p$ lbs. sq. in. from indicator diagram × area of piston (+ same for other pistons) × speed feet per minute ÷ 33,000,

$$\text{or } \frac{p.l.a.n}{33{,}000},$$

$p$ being mean pressure, $l$ length of stroke, $a$ area of piston, $n$ number of strokes per minute.

Rough estimate of I.H.P. of engine $= \left(\frac{\text{diam.}}{2}\right)^2$, which is correct for a mean effective pressure of 42 lbs. per sq. inch and piston velocity of 500 feet per minute.

### 514. Effective or Brake Horse-Power.

*Effective* H.P. = actual H.P. of work done, or useful effect given out from engine, either estimated, or found by friction brake, or by measurement of work performed. It is the net work done by the engine after deducting friction and loss. The effective H.P. of any engine, compared with the steam used, is the measure of its efficiency or economy.

*Brake* H.P. = the power given off from the crank shaft, through the fly-wheel, or a pulley, to an absorption or transmission dynamometer.

To ascertain Brake H.P. W = weight lbs., L = leverage feet, R = revolutions per minute.

$$\text{B.H.P.} = \frac{W\,L\,2\,\pi\,R}{33{,}000}.$$

### 515. French Horse-Power.

*French H.P.* (*Force de cheval* or *Cheval-vapeur*).

1 kilogrammètre = 1 kilogramme (2·205 lbs.) raised 1 mètre (3·281 feet) = 7·2346 foot-lbs.

1 kilogrammètre per second = 434 foot-lbs. per minute.

75 kilogrammètres per second, or 4500 kilogrammètres per minute = 32,550 foot-lbs. per minute, or about $\frac{1}{70}$ less than a British H.P., hence "*Chevaux de* 75 *kilogs.*"

French H.P. × ·9863 = British H.P.
British H.P. × 1·014 = French H.P.
*French I.H.P.* = *Cheval indiqué.*

### 516. Modulus of Steam Engine.

The modulus of a steam engine, or coefficient of mechanical efficiency, is found by dividing the effective or brake H.P. by the indicated H.P.

## 517. De Pambour's Principles.

1. When the engine has attained a uniform motion, the work done by the steam in the cylinder is equal to the work which is due to the total resistance.

2. The steam which is generated in the boiler is equal to that expended in the cylinder.

## 518. Steam Worked Expansively.

$p$ = absolute initial pressure.
$s$ = stroke.
$m$ = mean pressure.
$n$ = ratio of whole stroke to stroke before cut-off.

When cut off at any part of stroke, as $\frac{1}{n}$; then its

Efficiency $= 1 + \text{hyp. log } n$.

Mean pressure $= \frac{1}{n} p (1 + \text{hyp. log } n)$.

Initial pressure $= \dfrac{m\,n}{1 + \text{hyp. log } n}$.

Pressure at any point in the expansion curve at $x$ distance from commencement of stroke $= \dfrac{\frac{1}{n}s}{x} p$.

Advantage of working expansively $= 1 + \text{hyp. log } n$ to 1, or $100 \times \text{hyp. log } n$ per cent. gain.

Distance travelled to attain maximum velocity

$$= \frac{p\,s}{m\,n} \text{ or } \frac{s}{1 + \text{hyp. log } n}.$$

Cut-off for maximum efficiency (*Pole*)

$$= \frac{\dfrac{24{,}250}{p} + 65}{\dfrac{24{,}250}{\text{useless resistances}} + 65}.$$

Terminal pressure $= \frac{p}{n}$, or $\frac{1}{n}$th of $p$.

Units of work per sq. inch of piston in one stroke

$$= p\frac{s}{n}(1 + \text{hyp.} \log n).$$

All pressures are measured from perfect vacuum, the atmospheric line is a variable element.

Above formulæ assume theoretically perfect indicator diagrams and expansion according to Boyle and Marriotte's law.

In ordinary land engines the mean pressure found above must be multiplied by ·8 to give the mean pressure from an indicator diagram.

Clearance spaces each end = $\frac{1}{15}$ to $\frac{1}{20}$ cylinder capacity.

519. Table of Hyperbolic Logarithms.

| Cut-off. | No. | Hyp. Log. |
|---|---|---|
| $\frac{5}{6}$ | 1·2 | ·1823215 |
| $\frac{4}{5}$ | 1·25 | ·2231435 |
| $\frac{3}{4}$ | 1·33′ | ·2851788 |
| $\frac{2}{3}$ | 1·5 | ·4054652 |
| $\frac{3}{5}$ | 1·66′ | ·5068176 |
| $\frac{1}{2}$ | 2·0 | ·6931472 |
| $\frac{2}{5}$ | 2·5 | ·9162907 |
| $\frac{3}{8}$ | 2·66′ | ·9783260 |
| $\frac{1}{3}$ | 3·0 | 1·0986124 |
| $\frac{1}{4}$ | 4·0 | 1·3862943 |
| $\frac{1}{5}$ | 5·0 | 1·6094379 |
| $\frac{1}{6}$ | 6·0 | 1·7917595 |
| $\frac{1}{7}$ | 7·0 | 1·9459100 |
| $\frac{1}{8}$ | 8·0 | 2·0794414 |
| $\frac{1}{9}$ | 9·0 | 2·1972245 |
| $\frac{1}{10}$ | 10·0 | 2·3025851 |

Com. log × 2·3025851 = Hyp. log.
Hyp. log × ·434294819 = Com. log.

### 520. Mean Pressure without Logarithms or Scales.

To find mean pressure of theoretical indicator diagram (say at Exam.) without logarithms or scales. Example:—Cut-off at $\frac{6}{10}$ of stroke, then intermediate pressures will be as follows:

| | By Inside Rectangles. | By Outside Rectangles. |
|---|---|---|
| At 1st tenth | 1· | 1· |
| 2nd „ | 1· | 1· |
| 3rd „ | 1· | 1· |
| 4th „ | 1· | 1· |
| 5th „ | 1· | 1· |
| 6th „ | 1· | 1· |
| 7th „ = $\frac{6}{7}$ | ·857 | 1· |
| 8th „ = $\frac{6}{8}$ | ·75 | ·857 |
| 9th „ = $\frac{6}{9}$ | ·667 | ·75 |
| 10th „ = $\frac{6}{10}$ | ·6 | ·667 |
| | 8·874 | 9·274 |

```
      8·874
      9·274
   2)18·148     ∴ mean = ·9074 of boiler pressure.
   10)9·074
       ·9074
```

Checking this by hyp. log the multiplier = ·9041, so that the error is less than $\frac{1}{4}$ of 1 per cent.

### 521. Ordinates to Hyperbolic Expansion Curves.

Initial pressure = $p$.

Cut-off at $\frac{2}{10}$, then ordinate at $\frac{3}{10} = \frac{2}{3}\,p$.

„ „ $\frac{4}{10} = \frac{2}{4}\,p$.

„ „ $\frac{5}{10} = \frac{2}{5}\,p$, and so on.

Cut-off at $\frac{1}{4}$ ( $= \frac{5}{20}$), then ordinate at $\frac{3}{10}$ ( $= \frac{6}{20}$) $= \frac{5}{6}p$.
" " $\frac{4}{10}$ ( $= \frac{8}{20}$) $= \frac{5}{8}p$.
" " $\frac{5}{10}$ ( $= \frac{10}{20}$) $= \frac{5}{10}p$,
and so on.

## 522. Simpson's Rule.

For area of any irregular figure.

Divide area into any even number of parts by odd number of lines or ordinates. Take the sum of the extreme ordinates, four times the sum of the even ordinates, and twice the sum of the odd ordinates (omitting the first and the last ordinates) multiply the total by one-third of the distance betwen ordinates, this equals the area.

For indicator diagram, divide length into ten equal parts by eleven lines, measure effective length of each, and number them. Then

(1st + 11th) + 4 (2nd + 4th + 6th + 8th + 10th) + 2 (3rd + 5th + 7th + 9th) ÷ 30 = mean pressure,

## 523. Resistance in Steam Engines.

1. The load or useful work.

2. The friction of the unloaded engine = 1 to 3 lbs. per sq. inch.

3. Additional friction due to the load = say $\frac{1}{7}$ of mean pressure.

4. Back pressure = 4 to 5 lbs. absolute i.e. above perfect vacuum for condensing engines, or 15 to 18 lbs. absolute for non-condensing engines.

The coefficient or modulus will then be ·6 to ·75.

Generally the friction may be taken as 10 per cent. of the H.P. in a non-condensing engine, and 18 per cent. of the H.P. in a condensing engine.

The average friction of a stationary engine with shafting is considered to be = 3 lbs. per sq. inch of the boiler pressure; and of a marine engine, $1\frac{1}{2}$ lbs. per sq. inch.

### 524. Mean Effective Pressure, Compound Engine.

$m$ = mean effective pressure, supposing all work done in low pressure cylinder.

$p$ = boiler pressure by gauge.

$$m = \sqrt{6\,p}.$$

*J. Macfarlane Gray.*

### 525. Piston Constant for Indicator Diagrams.

When several are to be worked out the "piston constant" will be found useful, thus:

piston constant $= \dfrac{\text{area sq. ins.} \times \text{ft. stroke,}}{33,000}$ multiplied by 2 if same diagram is to answer for both ends of stroke, and by 2 again if to answer for 2 cylinders. Then,

I.H.P. = const. × mean press. lbs. per sq. in. × rev. per min.

In finding the effective pressure on the piston at any part of stroke, take steam pressure × area one side − back pressure × area other side. In an ordinary indicator diagram from one end of cylinder, the steam line and exhaust line belong to the same side of piston, and would therefore only give the effective pressure approximately.

### 526. Crank and Piston Notes.

$a$ = Length of connecting rod.

$b$ = Length of crank.

$x$ = Distance of piston from end of stroke furthest from crank, when point of maximum leverage is reached.

$x'$ = Distance as before, when crank has made quarter revolution from dead centre.

$$x = (a + b) - \sqrt{a^2 + b^2}. \qquad x' = (a + b) - \sqrt{a^2 - b^2}.$$

These values divided respectively by 2 $b$ will give the proportion of stroke where these points occur.

All the distances are measured from the end of stroke furthest from crank.

$p$ = pressure on piston (total).
$p_1$ = thrust in connecting rod.
$\theta$ = angle of connecting rod with horizontal.
$p_2$ = pressure on guide bar.
$p_3$ = turning effort on crank.
$\phi$ = angle of crank with horizontal, then *

$$\sin \phi = \sin \theta \frac{a}{b}$$

$$\sin \theta = \sin \phi \frac{b}{a}$$

$$p_1 = p \times \text{cosec } \theta$$
$$p_2 = p \times \tan \theta$$

Between tangential points in 1st and 4th quadrants,

$$p_3 = p \times \cos \theta \times \sin (\phi + \theta).$$

Beyond do. do. through 2nd and 3rd quadrants,

$$p_3 = p \times \text{cosec } \theta \times \sin (\phi - \theta).$$

$d$ = distance as before for any angle of crank

$$= b + a - (b \cos \phi + \sqrt{a^2 - b^2 \sin^2 \phi}.$$

$$\cos \theta = \sqrt{1 - \frac{b^2}{a^2} \sin^2 \phi}.$$

$$\frac{\text{Velocity of piston}}{\text{Velocity of crank pin}} = \frac{\sin (\phi + \theta)}{\cos \theta}.$$

* For a simple introduction to Trigonometry, see the author's 'Practical Trigonometry' (Whittaker & Co., 2s. 6d. net).

Approximately the maximum pressure on guide bar may be found thus:

Length con. rod : length crank : : press. on piston : press. on guide bar.

Pressure on guide bar should be limited to from 100 to 400 lbs per sq. inch.

Piston speed = twice stroke feet × revolutions per minute.

### 527. Slide Valves, Explanation of Terms.

*Travel* of slide valve is twice throw of eccentric where connected direct, and should not be less than 2 (outside lap + steam port).

*Lap, outside lap, steam lap,* or *cover* is the distance the slide reaches beyond outer edge of steam port when in centre of travel.

*Inside lap,* or *exhaust lap,* is the distance from inside edge of steam port to edge of slide port, or space in slide, when in centre of its travel.

*Negative, or minus, inside lap* occurs when both steam ports are open to the exhaust in the central position, sometimes found in quick-running engines.

*Lead* is the amount of opening of steam port by slide when piston is at commencement of stroke, due to eccentric being set in advance of crank. Generally equal each end and varying from $\frac{1}{32}$ inch to $\frac{1}{4}$ inch. Inverted engines usually set with more lead at bottom than top, to allow for dropping of slide due to wear, and to equalise the diagrams.

*Angular advance* of eccentric is lap + lead, set off from centre, along centre line of crank, and transferred perpendicularly on to circumference of throw circle.

*Width of face* of slide valve = width of steam port + steam lap + exhaust lap.

*Amount of opening of port,* steam or exhaust, = half travel − lap.

## 528. Area of Steam Ports.

A = area of piston.
$a$ = area of steam port.
$b$ = area of exhaust port.
$v$ = velocity of piston feet per minute.

$$a = \frac{v\,A}{4800}.$$

$$b = \frac{v\,A}{6000} + \text{part covered.}$$

*Baker* (Weale's Series, 'Steam Engine,' p. 71): Watt's condensing engines, $a = 1$ sq. inch per N.H.P.

*Bourne* ('Hbk. Steam Engine,' p. 313): $a = 1$ sq. inch per N.H.P. or $\frac{1}{25}$ A. Also $a$ = diam. cylr.$^2 \times v \times \cdot 032 \div 140$.

*Burgh* ('Slide Valve,' p. 10): high press. engine, $a$ = H.P. $\times \cdot 6$ or $\cdot 5$. Low press. engine, $a$ = H.P. $\times$ 1 $\cdot$ to $\cdot 75$.

*Rankine* ('Steam Engine,' p. 414): $a = \frac{1}{25}$ A for $v$ 200 to 240.

*Sir W. G. A. & Co.*: $a = \frac{1}{24}$ A, $b = 2\,a$, $v = 200$.

*Adams*, $a = \frac{1}{15}$ to $\frac{1}{12}$ A, $b = 1\frac{3}{4}\,a$, $v = 350$ to 500.

*Shapton*, $a$ = diam. cylr.$^2 \times \cdot 038$.

*Rigg*, $a = A \times v \div 6000$.

Thickness of bar between ports = $\cdot 5$ steam port, minimum 1 inch, or = thickness of metal in cylinder.

Length of steam port should be in proportion to diameter of cylinder, say $\cdot 6$ to $\cdot 8$ cylinder diameter. To shorten travel, increase length of port.

Locomotives and other fast running engines should have the lap a little over $\frac{1}{5}$ of the travel, and lead $\frac{1}{14}$ travel.

—*Bourne.*

Ordinary engines with simple D slide, lap = $\frac{1}{4}$ travel and cut-off at $\frac{2}{3}$ stroke.

## 529. Slide Valve Notes.

$r$ = ratio of cut-off in cylinder.
T = travel of slide.
L = lap ,,
$l$ = lead ,,
$w$ = width of steam port.

$$T = 2\,(w + L).$$

$$L = (\tfrac{1}{2}\,T\,\sqrt{1 - r}) - \tfrac{1}{2}\,l.$$

$$r = 1 - \left(\frac{2\,L + l}{T}\right)^2.$$

Effect of obliquity of connecting rod is to make cut-off later on the outdoor stroke and earlier on the indoor stroke, or, in other words, to draw all points of an indicator diagram nearer the crank or stuffing-box end of a cylinder.

### 530. Point of Cut-off

when slide is set with equal lead

A = distance travelled by piston before cut-off.

B = remainder of stroke.

C = distance centre crosshead to centre crank shaft at point of cut-off $= a + b -$ A.

Cut-off on outdoor stroke = A.

Do. indoor „ $= A - \dfrac{A \times B}{C}$.

To equalise cut-off, shift slide.

### 531. Number of Expansions.

The steam is usually expanded in

| | | | | | |
|---|---|---|---|---|---|
| Simple condensing engines | from | 3 | to | 5 | times. |
| Two cylinder compounds | „ | 7 | „ | 9 | „ |
| Triple compounds | „ | 12 | „ | 15 | „ |
| Quadruple compounds | „ | 16 | „ | 18 | „ |

The total expansion is found by dividing the capacity ($d^2\,l$) of the low-pressure cylinder up to point of release by the capacity ($d^2\,l$) of high pressure cylinder up to point of cut-off. Intermediate cylinders do not affect the ratio.

### 532. Triple Expansion Engines.

Theoretical terminal pressure should be about $12\frac{1}{2}$ lbs. absolute.

Cut-off in H.P. (high pressure) cylinder should be about half stroke.

$$\text{Ratio of capacity } \frac{\text{L.P.}}{\text{H.P.}} = \text{abs. br. press.} \times \cdot 04$$
$$= \text{say } 6\tfrac{1}{2}.$$
$$\text{Do. } \quad \frac{\text{I.P.}}{\text{H.P.}} = \text{say } 2\tfrac{1}{2}.$$
$$\text{Do. } \quad \frac{\text{L.P.}}{\text{I.P.}} = \text{not less than } 2\tfrac{1}{2}.$$

Approximately, in a triple expansion engine 13 lbs. water converted into steam of 175 to 200 lbs. pressure will give 1 horse-power.

### 533. Cylinder Ratios.

*Two-cylinder compounds.*

$p$ = initial pressure in cylinder, say 5 lbs. less than boiler.

$n$ = number of tenths up to cut-off in high-pressure cylinder.

$$r = \frac{p\,n}{105}.$$

*Triple compounds.*

$p$ = gauge pressure, from say 125 to 175.

$r$ for small $= 1$

,, intermediate $= \cdot 015\,p + \cdot 3$

,, large $= \cdot 075\,p - 4 \cdot 75.$

### 534. Advantage of Steam Jacketing.

Triple expansion engine indicating 175 H.P. at 55 revolutions per minute with 120 lbs. boiler pressure.

| | | | | |
|---|---|---|---|---|
| High-pressure | jacket | alone gave | $1\frac{1}{4}$ | per cent. gain. |
| Intermediate | " | " | $2\frac{1}{4}$ | " |
| Low-pressure | " | " | $6\frac{1}{2}$ | " |

Best result with boiler steam in all three jackets was 14·1 lbs. steam per I.H.P. per hour (including jacket steam) with 146 lbs. boiler pressure and 61 revolutions per minute.
—*B. Donkin.*

Steam jacketing prevents much of the condensation in the cylinder, which takes place in the jacket instead. Its usefulness is greater as the expansion is greater, owing to the increased range of temperature.

### 535. Link Motions.

*Stephenson's.*—Link curved, concave side towards eccentrics, shifted to vary position of motion block, block moving in direct line with slide rod, lead increasing towards midgear with open rods and decreasing with crossed rods. Length of link three times travel of valve.

*Gooch's.*—Link curved, concave side towards spindle, maintained in central position by rod swinging on a stud, motion block shifted in link by radius rod connected to valve spindle, lead constant.

*Allan's.*—Link straight, link and motion block moved in opposite directions by rocking shaft, lead increasing towards mid-gear with open rods, and decreasing with crossed rods.

*Joy's.*—Link curved, moving on a fixed pivot, concave side towards valve, no eccentrics; pendulum rod attached to centre of connecting rod at one end and to radius bar at other end; another bar pivoted on motion block, one end

connected to valve rod and other end to pendulum rod; link moved on centre to alter valve; distribution of steam symmetrical.

### 536. Radial Valve Gears.

A radial valve gear has been defined as one in which the motion is taken from some point of a vibrating link, a second point of which moves in a closed curve, while a third point moves in a straight line or open curve, but the characteristic feature is rather in the mode of reversing. The link motions reverse by moving the free end of the valve radius rod, with its sliding piece, to one side or the other of the centre of an oscillating link. The radial gears reverse by altering the path of the fulcrum point in the valve lever or vibrating link.

### 537. Watt's Governor,

commonly called a pendulum governor, usually makes 30 revolutions per minute; then $h = 39 \cdot 1$ inches = length of London seconds pendulum. Whole arm 3, upper portion 2, link 2, variation of velocity 10 per cent. Weight of ball $= 3 \cdot 174 \times$ resistance of throttle valve connections. Generally:

$w$ = weight required to open throttle valve in lbs.
W = weight of one ball of governor in lbs.
L = whole length centre of suspension to centre of ball in inches.
$l$ = length from centre of suspension to centre of attachment of link in inches.
$h$ = height from centre line of balls when rotating at given speed to centre of suspension in inches.
R = revolutions per minute of governor.

$$h = \frac{35225}{R^2}, \qquad W = \frac{100\,l\,w}{10\,L}, \qquad R = \frac{187 \cdot 68}{\sqrt{h}}.$$

Weight of cast-iron ball $= \dfrac{d^3}{7 \cdot 27}$. Diam. $= \sqrt[3]{7 \cdot 27\ W}$.

—*Hann.*

*Note.*—In the Watt governor, the virtual point of suspension does not coincide with the actual points, owing to the pendulum arms being pivoted to projecting lugs at top of spindle. For accurate work the measurements should be taken to the virtual point of suspension, which is found by producing the centre line of pendulum rods to intersect with vertical axis.

### 538. Efficiency of Governor.

The height of a Watt governor is measured from the plane of rotation of the balls to the intersection of the direction of the arms, and therefore, in the ordinary construction, it reduces as the balls fly out, whence the efficiency also reduces.

In Head's governor the arms are continued through the spindle and pivoted beyond, so that as the balls fly out the height is slightly increased and also the efficiency.

### 539. Fly-wheels, Notes and Formulæ.

F = total centrifugal force in lbs. radially

$$= \frac{W\,v^2}{r\,g} = \cdot 00034\,r\,W\,R^2$$

= total tension in arms to be divided by number of arms for tension in each.

$d$ = mean diameter and $r$ = mean radius of rim in feet.
W = weight of rim in lbs.
R = revolutions per minute.

Tension at any cross section of rim in lbs. per sq. inch

$$= \frac{F}{2\,\pi} \quad \text{(safe limit = 2500 lbs.);}$$

also $= \dfrac{v^2}{10}$ approx. $\left\{ \begin{array}{l} \text{(where } v = \text{linear velocity ft. per sec.;} \\ \text{max.} = 80 \text{ feet per sec. for cast iron).} \end{array} \right.$

M = foot-lbs. momentum at 1 revolution per minute.
U = units of work (foot-lbs.) accumulated in fly-wheel at any velocity.

$$M = \frac{W\, d^2}{23000}. \quad U = M\,R^2.$$

E = excess of demand or supply in any given time in foot-lbs.

R max. R min. = greatest variation allowed in speed, i.e. revolutions per minute.

$$M = \frac{E}{R^2 \text{ max.} - R^2 \text{ min.}}$$

The diameters of fly-wheels will be as $\sqrt[5]{M}$, the dimensions of rim being proportional to diameter.

—*Perry.*

$n$ = number of revolutions per second.
$r$ = effective radius of gyration in feet.
U = units of work stored in wheel.

$$U = \frac{W\,(2\,\pi\, r\, n)^2}{2\,g}.$$

Variation from mean velocity not to exceed $\frac{1}{m}$, usually $\frac{1}{20}$ to $\frac{1}{60}$.

$a$ = area of section of rim in sq. inches.

$$a = \frac{\text{H.P.} \times 1803 \times m}{r^3 \times R^3}.$$

$$\text{Weight in tons} = \frac{\text{H.P.} \times 2275 \times m}{r^2 \times R^3}.$$

$$\text{Mean radius} = \frac{12 \cdot 17}{R} \times \sqrt[3]{\frac{\text{H.P.} \times m}{a}}.$$

—*Morin.*

$R$ = revolutions per minute.
$A$ = sectional area rim sq. feet.
$r$ = radius feet to inside of rim.
$H$ = I.H.P. of engine.
$n$ = ratio of mean velocity to difference between mean and either extreme (say 10 for a difference of 10 per cent.).

$$r = \frac{12}{R} \times \sqrt[3]{\frac{n\,H}{A}}.$$

—*O. Byrne.*

Ultimate velocity at centre of gravity of rim to produce bursting = 19,235 feet per minute; ∴ safe velocity, say 5000 feet per minute. —*C. E. Emery.*

U foot-lbs. energy required to be given out in $t$ seconds or revolutions, when $s$ seconds or revolutions can be used to restore it, will require an average of E foot-lbs. in fly-wheel.

$$E = \frac{s}{s+t} \times U.$$

And if the variation of velocity must not exceed $c$ per cent. on either side of $v$, mean velocity in feet per second when running at $n$ revolutions per minute,

$$v = \frac{2\,\pi\,r\,n}{60},$$

$$v_{max} = \frac{v\,(100+c)}{100}, \qquad v_{min} = \frac{v\,(100-c)}{100},$$

and the necessary weight W of fly-wheel rim will be

$$W = \frac{E\,2\,g}{v^2_{max} - v^2_{min}}.$$

—*Allen.*

Fly-wheels may be designed for an accumulated energy equal to the foot-lbs. given out by the engine in three revolutions. —*Hendry.*

$P$ = total average pressure on piston in lbs.
$S$ = stroke in feet.
$D$ = mean diameter of rim in feet.
$W$ = weight of rim in cwts.
$A$ = sectional area of rim in sq. inches.

$$W = \frac{P\,S}{45\,D}, \qquad A = \frac{1 \cdot 42\,W}{D}.$$

Multiply by 1·5 when cut off earlier than $\frac{1}{2}$ stroke. Diameter usually $3\frac{1}{2}$ to 4 times stroke of engine. Maximum safe circumferential velocity 80 feet per second.

—'*Practical Engineer Pocket Book.*'

## 540. Investigation of Fly-Wheels.

$\frac{W}{g}$ = mass ($m$), $\frac{v^2}{2\,g}$ = height ($h$), kinetic energy = $\frac{1}{2}\,m\,v^2$, potential energy = $W\,h$, accumulated work = $\frac{W\,v^2}{2\,g}$, then

$$\frac{W\,v^2}{2\,g} = W\,h = \tfrac{1}{2}\,m\,v = M\,R^2$$

but

$$v^2 = \left(\frac{2\,\pi\,r\,R}{60}\right)^2 = R^2\left(\frac{2\,\pi\,r}{60}\right)^2 \therefore \frac{W}{2\,g}\left(\frac{2\,\pi\,r}{60}\right)^2 = M,$$

or

$$W\,r^2\,\frac{4 \times 9 \cdot 87}{3600 \times 64 \cdot 4} = \frac{W\,r^2}{5871} = M.$$

$$\therefore \text{Energy of fly-wheel} = \frac{W\,r^2}{5871} \times R^2.$$

Energy stored up in any rotating body = $\frac{1}{2}\,I\,a^2$, where $I$ = moment of inertia about the axis = $\Sigma\,m\,y^2$, $a$ = any velocity in radians per second.

$$a = \frac{2\pi R}{60} \qquad \therefore \text{ Energy} = \tfrac{1}{2} I \left(\frac{2\pi R}{60}\right)^2 = I \frac{\pi^2 R^2}{1800}.$$

$$\therefore \text{ M of fly-wheel} = \frac{I\pi^2}{1800} = \cdot 00548\, I.$$

But

$$\text{M of fly-wheel} = \frac{W r^2}{5871}. \qquad \therefore \cdot 00548\, I = \frac{W r^2}{5871},$$

and

$$I = \frac{W r^2}{5871 \times \cdot 00548} = \frac{W r^2}{32 \cdot 17}.$$

### 541. Strength of Crank Pin.

$p$ = uniformly distributed load in lbs.
$l$ = length of journal in inches.
$d$ = diameter of journal in inches.
$f$ = greatest safe stress per sq. inch.

| | | |
|---|---|---|
| Say, wrought iron | . . . | 6000 to 9000 |
| steel | . . . . . | 9000 to 13500 |
| cast iron | . . . . | 3000 to 4500 |

$\frac{p\,l}{2}$ = greatest bending moment at fixed end of journal.

$$M = \frac{\pi}{32} d^3 = \cdot 0982\, d^3 = \text{modulus of circular sec.} = \frac{2\,I}{d}.$$

$$I = M\frac{d}{2} = \frac{\pi}{32} d^3 \times \frac{d}{2} = \frac{\pi}{64} d^4 = \cdot 0491\ d^4 = \text{moment of inertia of circular section.}$$

$$p = \cdot 0982\, d^3 f \frac{2}{l} = \frac{\cdot 1964\, d^3 f}{l} = \frac{d^3 f}{5 \cdot 1\, l}.$$

$$d = \sqrt[3]{\frac{p\,l}{\cdot 1964\, f}} = \sqrt[3]{\frac{5 \cdot 1\, p\,l}{f}}.$$

## 542. Fly-Wheel Shaft for Rolling Mill.

$d$ = diameter steel shaft, inches.
W = weight fly-wheel, tons.
S = span between bearings in feet.

$$d = 3\sqrt[3]{\frac{\mathrm{W\,S}}{2}}.$$

## 543. Calculation of Engine Shafts.

By law of virtual velocities, mean pressure on crank pin

$$= d^2\frac{\pi}{4} \times m \times \frac{2\,s}{\pi\,s} = \frac{d^2\,m}{2} = \frac{a\,m}{1\cdot 57};$$

but the force being irregular, the maximum must be taken for the crank and fly-wheel shaft; say full pressure on piston acting at radius of crank,

$$= \frac{d^2\,\pi\,p}{4} \text{ at radius } \frac{s}{2}.$$

Beyond the fly-wheel $\frac{d^2\,m}{2}$ may be substituted for $\frac{d^2\,\pi\,p}{4}$, as the strain will there be practically uniform.

$p$ = maximum boiler pressure, lbs. per sq. inch.
$m$ = mean pressure in cylinder ,,
$s$ = stroke of piston in feet.
$d$ = diameter ,, inches.
$a$ = area ,, sq. inches.
$f$ = factor of safety.

| | Steam engine. | Hydc. eng. and steam winches. |
|---|---|---|
| Wrought iron and steel . | $\frac{1}{6}$ | $\frac{1}{10}$ |
| Cast iron . . . . . | $\frac{1}{10}$ | $\frac{1}{15}$ |

$k$ = ultimate strength, 1-inch bar, 1 foot radius.

| | Cast steel. | Mild steel. | Wrought iron. | Cast iron. |
|---|---|---|---|---|
| | 1250 | 1000 | 750 | 600 |
| $c$ = constant or safe load = $fk$. | | | | |
| Steam engine . | 200 | 175 | 125 | 60 |
| Hydraulic engine &c. | 125 | 100 | 75 | 40 |

D = diameter of shaft in inches.

For crank shaft:

$$D = \sqrt[3]{\frac{d^2 \times \pi \times p \times s}{4 \times 2 \times f \times k}} = \sqrt[3]{\frac{d^2 p s}{2 \cdot 5 c}}.$$

And beyond the fly-wheel:

$$D = \sqrt[3]{\frac{d^2 \times m \times s}{\times 2 \quad \times f \times k}} = \sqrt[3]{\frac{d^2 m s}{4 c}}.$$

For two cylinders, let diameter = D + ·15 D.
For three cylinders " = D + ·3 D.

## 544. Steam Engine Dimensions.

$t$ = thickness in inches.
$d$ = diameter "
$p$ = boiler pressure, lbs. per sq. inch.
A = area of piston in sq. inches.
S = length of stroke in inches.
D = diameter of piston "

Cylinder walls, $t = \frac{p\,D}{4000} + \cdot 5.$

" covers, $t = \frac{1}{8}$ inch thicker than cylinder, and stiffened as required.

Cover studs, $d$ = maximum stress on net section, 2000 lbs. per sq. inch, minimum diameter = $\frac{5}{8}$ inch.

Cylinder flange, $t$ = diameter studs $\times 1\frac{1}{2}$.

Pitch of studs, $\sqrt{\frac{100\,T}{p}}$

(T being thickness of cover in sixteenths).

Piston rod, $d = \cdot 0167\,D\,\sqrt{p}$ if iron,

$= \cdot 0144\,D\,\sqrt{p}$ if steel.

Crank shaft, if well supported, $d = \sqrt[3]{\frac{A\,p\,S}{3600}}$.

Connecting rod, length $= 3$ S.

Crosshead pin, diameter $= d$ piston rod $\times 1 \cdot 25$

" length = do. $\times 1 \cdot 4$.

Crank pin, diameter $= \sqrt[3]{\frac{A\,p\,l}{1800}}$ ($l$ = lgth. = $1\frac{1}{2}$ diam.)

Pressure on bearing surfaces = 400 lbs. per sq. inch.

A practical rule for thickness of steam cylinder for small engines $= \frac{1}{6}\sqrt{d} +$ thickness for re-boring, with a minimum of $\frac{5}{8}$ in.

### 545. Condenser and Air Pump.

In the old jet or spray condenser, the air pump had to remove at each stroke the water used by the engine as steam and also the condensing water. In the surface condenser only the former has to be removed by the air pump, the circulating pump dealing with the water producing condensation. In the multitubular surface condensers, the water producing condensation passes through the tubes while the steam is in contact with the outside, or *vice versâ*.

### 546. Circulating Pump.

The quantity of water provided by the circulating pump must be such that its velocity through the condenser tubes is sufficient to abstract the heat from the steam and convert it to water in the hot-well at a suitable temperature for re-transfer to the boiler by the air pump. The heat gained by the circulating water is equal to the heat lost by the steam.

In order to obtain rapid condensation, the quantity of injection water supplied is usually about thirty times the weight of steam to be condensed.

### 547. Circulating Water for Condensation.

The ordinary surface condenser requires 30 lbs. circulating water to condense 1 lb. steam. The Körting self-acting condenser without regulation requires 25 lbs. water, and with regulation 18 lbs. water, to condense 1 lb. steam.

### 548. Comparison of Steam Engines.

Engines same type. Boiler pressure same. Cut-off same. Multiplier for proportionate linear dimensions equals

$$\sqrt{\frac{\text{required H.P.}}{\text{original H.P.}}} = \sqrt{r},$$

and the revolutions per minute will be

$$\frac{\text{original revolutions}}{\sqrt{r}},$$

without allowing for difference in proportion of friction. Friction varies approximately as $\sqrt[3]{r}$.

### 549. Marine Engines.

Marine engineers' rule for engines of varying power, but same type:

Required cylinder diameter =

$$\sqrt{\frac{\text{reqd. H.P.}}{\text{orig. H.P.}} \times \frac{\text{orig. pist. speed}}{\text{reqd. pist. speed}} \times \left(\frac{\text{orig. cylr.}}{\text{diam.}}\right)^2}.$$

*Examples.*

I.H.P., 6000.
Cylinder 43, cut-off $8\frac{1}{2}/10$.
„ 62 „ $8\frac{1}{2}/10$.
„ 96 „ $8/10$.
Piston rods same size.
Stroke, 4 feet 3 inches.
Boiler pressure, 135.
Revolutions, 95.
Piston speed, 807·5.

I.H.P., 2750.
Cylinder 30, cut-off $8\frac{1}{2}/10$.
„ 44 „ $8\frac{1}{2}/10$.
„ 68 „ $8/10$.

---

Stroke, 3 feet.
Boiler pressure, 135.
Revolutions, 130.
Piston speed, 780.

### 550. Definitions relating to Screw Propellers.

*Length* = $A^1 B^1$ measured along the axis of the shaft.

*Angle* = P O H, which is a plane triangle when developed.

*Pitch* = the distance traversed on $A^1 B^1$ for one complete revolution of $A^1 P$.

*Slip* = the difference between the theoretical forward motion, calculated from the pitch of the screw, and the actual progress of the ship.

*Area* = $A^1$ P O B, surface of blade in sq. feet.

*Thread or Helix* = Outer edge of blade, O P.

*Diameter* = Diameter of cylinder circumscribing the thread of screw. $A^1 P$ = radius.

### 551. Speed in Knots.

$$\text{Speed in knots} \times 1{\cdot}15 = \text{miles per hour.}$$

$$6080 \text{ feet} = 1 \text{ knot.}$$
$$5280 \text{ „} = 1 \text{ mile.}$$

$$\text{Feet per minute} \div 88 = \text{miles per hour.}$$
$$\text{„} \quad \div 101\tfrac{1}{3} = \text{knots} \quad \text{„}$$

Speed of ship in knots (per hour)

$$= \sqrt[3]{\frac{\text{I.H.P.} \times \text{sectional coeff. of performance, say } 600}{\text{area immersed midship section, sq. feet}}},$$

or

$$= \sqrt[3]{\frac{\text{I.H.P.} \times \text{displacement coeff. of performance, say } 240}{\text{cube root of sq. of displacement in tons}}}.$$

### 552. Notes on Screw Propellers.

In the common form of propeller the screw surface is generated by a line perpendicular to the axis of the shaft revolving round the shaft and progressing uniformly along it.

Screw surfaces are also generated by a line at right angles to a conical surface; in some cases the vertex of the cone points aft, and in others forward. In some the surface is traced out by a line perpendicular to a sphere; the object in such cases being to diminish, if possible, centrifugal action of the water.

Screws of same pitch have different angles if their diameters differ; angle reducing as diameter increases.

The screws are either right or left-handed, and may have two, three, or four blades.

### 553. Relative Efficiency of Large and Small Screw.

"As regarded the relative efficiency of large and small screws, if consideration were confined to the propellers alone, apart from the vessels they were designed to propel and the services they were intended to perform, efficiency was independent, within certain limits, of the absolute size of the screw. According to Mr. Froude, the screw for a vessel of 500 I.H.P., and 10 knots speed per hour, might be 10 feet in diameter, 0·8 pitch-ratio, and run at 138 revolutions per minute; or it might be 15½ feet in diameter, 2·5 pitch-ratio, and run at 33½ revolutions. Both screws would be credited with an

efficiency of 69 per cent.; but the large screw was at a disadvantage when placed in a following stream, on account of the greater difference in the velocity of wake currents which it experienced, and also because of its greater liability to emerge from the water. To maintain a high speed against head winds and sea, a relatively large screw was desirable; the case was analogous to that of a tug. For such a purpose increased diameter should not be associated with increased pitch-ratio."

### 554. Slip of Screw Propeller.

Slip is less when pitch is small and speed great, but more danger from heated bearings. When pitch is small, the propeller is less liable to break from a blow.

The slip is diminished, *cæteris paribus*, by

1. Decreasing the angle of the screw.
2. Increasing the diameter of the screw.
3. Increasing the length of the screw.

But the friction increases rapidly with the surface of the blade.

The indicated horse-power varies as the square of the speed of the ship × number of revolutions of screw × pitch.

The most economical speed is when the vessel steams half as fast again as the opposing current, or half as fast again as a vessel it desires to overtake.

### 555. Negative Slip.

Negative slip in screw propellers is caused either by the skin friction of the ship giving a forward velocity to the water in which the screw works, depending upon the lines of the ship, and the position and size of screw; or it is caused by an increase of pitch due to the straining of a weak propeller by the pressure of the water; or it is due to the pitch of the propeller being incorrectly estimated.

### 556. Pitch of Screw Propeller.

Ordinary propellers have the pitch uniform throughout each blade, the angle varying with the distance from the axis, originally known as Smith's propeller.

Screws of increasing pitch are sometimes used, and known as Woodcroft's propeller.

Propellers with two blades are common in large ships, but those with three or four blades are better when the draught is small or in a rough sea.

Feathering-screws have the blades pivoted so that the angle, and thereby the pitch, may be altered.

The pitch of a screw varies with the ratio of the circle described by the screw to the immersed midship section.

### 557. Relation of Pitch to Diameter.

There does not appear to be any advantage in adhering to a fixed relation of pitch to diameter. Dimensions rather than form regulate the efficiency. In Thorneycroft's experiments it was found that—

1. The disc-area was proportional to the I.H.P. and inversely proportional to the cube of the speed.

2. The revolutions per minute were proportional to the speed, and inversely proportional to the diameter.

3. The constants were of the form

$$C_A = \text{disc area} \times \frac{V^3}{\text{H.P.}},$$

$$C_R = \text{revolutions} \times \frac{D}{V}.$$

when $V$ = speed of screw through the water
$D$ = diameter of screw in feet.
H.P. = effective H.P. in screw shaft.

### 558. Formula for Pitch of Propeller.

C = constant.
= 737 ordinary mercantile marine.
= 600 cargo ships with full run.
R = revolutions per minute.
D = diameter propeller in feet.

$$\text{Pitch in feet} = \frac{C}{R}\sqrt[3]{\frac{\text{I.H.P.}}{D^2}}.$$

The pitch should never exceed $2\frac{1}{2}$ times diameter.

Another rule :—

Blade surface = 35 per cent. of disc area.
Breadth of blade = $\frac{1}{6}$ pitch.
Ratio pitch to diameter, average $1\frac{1}{3}$ to 1.
Coarse pitch requires more surface than fine pitch.

—'*Mechanical World.*'

### 559. Alteration of Pitch.

With same mean pressure on piston, for small alterations of pitch

$$\text{pitch} \times \text{knots}^2 = \text{constant}.$$

and

$$\text{pitch}^3 \times \text{revolutions}^2 = \text{constant}.$$

$\therefore$ increasing pitch reduces revolutions and speed.

—*Somerscales.*

### 560. Indicated H.P. Required for Screw Propeller.

R = revolutions per minute.
D = diameter of propeller in feet.
L = length " "
P = pitch " "
$s$ = slip " in fraction of unity (as $\frac{1}{4}$).
$\theta$ = angle of blade at periphery.

$$\text{I.H.P.} = \frac{D^3 R^3}{480{,}000}\left(L\,s\cos\theta + \frac{1}{9}\right).$$

$$\text{Knots (per hour)} = \frac{3\,P\,R}{304}(1 - s).$$

### 561. Built-up Crank Shafts.

*City of Rome* s.s., Whitworth compressed steel. Difference in diameter of fitting parts allowed for shrinkage $= \frac{1}{1000}$ diameter.

### 562. Steam Ships.

*Scott Russell's rules.*—

Greatest speed in knots $= \sqrt{2\frac{1}{2} \text{ times length of after body}}$.

At moderate speeds, resistance in lbs. = speed knots² $(\sqrt[3]{\text{displacement tons}})^2 \times \cdot 8$ to $1 \cdot 5$.

$$\text{Effective H.P.} = \frac{\text{resistance lbs.} \times \text{speed knots}}{326}.$$

$$\text{Indicated H.P. average} = \frac{\text{resistance lbs.} \times \text{speed knots}}{200}.$$

$$\text{Twin screws, dimensions} = \frac{\text{single screw}}{\sqrt{2}}.$$

" revolutions = single screw $\times \sqrt{2}$.

### 563. Paddle Wheels.

$k$ = speed of vessel in knots.
N = revolutions of engine per minute.
$r$ = radius of rolling circle in feet, or circle with circumferential velocity equal to ship's motion.

$$\frac{6080\,k}{60} = 2\,\pi\,r\,\text{N}.$$

$$\therefore \quad r = \frac{6080\,k}{60\,\pi\,2\,\text{N}} = \frac{16\,k}{\text{N}}.$$

R = radius outside wheel in feet.
$b$ = breadth radially of float-board or paddle in feet.
$m$ = mean radius, to centre of gyration, of float-boards.

$$m = r - b + \sqrt[3]{\frac{(\text{R} - r + b)^4}{4\,b}}.$$

$v$ = circumferential velocity of centre of pressure of float-boards in feet per second.

$$v = \frac{2\,m\,\pi\,N}{60} = \cdot 10472\,m\,N.$$

$a$ = area of float-boards in sq. feet.

$p$ = pressure in lbs. on vertical float-board.

$$p = \frac{62\cdot 5\,a}{2\,g} \times \left(v - \frac{6080\,k}{3600}\right)^2 = a\,(v - 1\cdot 7\,k)^2.$$

$n$ = number of paddle wheels.

$$\text{Effective H.P. required} = \frac{v\,n\,p}{33,000}.$$

—*Hann and Gener.*

### 564. Efficiency of Paddle Wheels.

| | | |
|---|---|---|
| Common, light draught . . . . | = | ·666 |
| „ deep „ . . . . . | = | ·553 |
| Feathering (Morgan's patent) all depths | = | ·666 |

### 565. Equilibrium of Floating Bodies, as Ships.

When a floating body is in equilibrium, the centre of gravity of the body and the c.g. of the displaced fluid are in the same vertical line. When the floating body is moved through a small angle, the intersection of the originally vertical line through c.g. of body, with vertical line through c.g. of now displaced fluid, is called the *metacentre* (Bouguer). The floating body will return to its original position so long as the metacentre remains above the c.g. of body. The equilibrium is stable, unstable, or indifferent, respectively, as the metacentre falls above, below, or coincides with the c.g. of the body.

When a body floats on a fluid it displaces a quantity equal in weight to itself, and when it sinks it displaces a quantity equal in bulk.

## 566. Displacement of Ships.

Length × breadth × draught × coefficient of fineness = displacement, e.g. H.M. *Blake.*

$$375 \times 65 \times 25{\cdot}75 \times {\cdot}502 = 9000 \text{ tons.}$$

Admiralty displacement formula,

$$c = \frac{D^{\frac{2}{3}} V^3}{\epsilon},$$

is not correct, it should be

$$\log \epsilon = \log \frac{D^{0{\cdot}6} V}{c} + a V.$$

—*R. Manuel.*

## 567. Tractive Force of Locomotives.

$d$ = diameter of piston in inches.
$a$ = area of piston in sq. inches.
$l$ = length of stroke in feet.
$n$ = number of cylinders.
D = diameter driving wheel in feet.

Then the tractive force at circumference of driving wheels for each lb. per sq. inch mean effective pressure on piston

$$= \frac{2anl}{\pi D}, \quad \text{or} \quad = \frac{d^2 l}{D}.$$

Also let $\mu$ = adhesion of wheels to rails (say ·2)
W = weight on driving wheels,
then W $\mu$ = maximum possible tractive force.

The greatest mean effective pressure on piston is commonly assumed to be 85 per cent. of boiler pressure, but this will be different for each design of valve gear, other things being equal. The ordinary mean effective pressure on piston would probably not exceed 50 per cent. of boiler pressure. The tractive power of a locomotive decreases as the speed increases.

T = traction in lbs. for two cylinders.
$p$ = boiler pressure lbs. per sq. inch.
$d$ = diameter of piston in inches.

$l$ = stroke in inches.
D = diameter driving wheel in inches.
K = coefficient = ·65 for cut-off at $\frac{3}{4}$ths.

$$T = K\frac{p\,d^2\,l}{D}.$$

—*De Pambour.*

H.P. of locomotive = tractive force lbs. × V miles per hour

$$\times \frac{5280}{60 \times 33{,}000} = \frac{88\,T\,V}{33{,}000}.$$

### 568. Adhesion of Locomotive Wheels.

Locomotive driving wheels will commence to slip if the force at circumference equals about

| | |
|---|---|
| $\frac{1}{5}$ of the load . . . | = 448 lbs. per ton. |
| Westinghouse and Galton . | = 246·4 ,, |
| Poirée . . . . . | = 465·9 ,, |
| Pennsylvania Railroad . | = 550 ,, |
| Northern Pacific Railroad . | = 670 ,, |

—*Eng. Mech.*

Adhesion depends principally upon the state of the weather, and varies from a maximum of $\frac{1}{4}$ load to a minimum of $\frac{1}{10}$ load, average say $\frac{1}{6}$ load.

### 569. Resistance on Railways.

Straight and level railway, in good condition, resistance (R) in lbs. per ton of total load (W).

$$= \frac{v \text{ miles per hour}^2}{171} + 8.$$

Do. on incline of 1 in $m$ = R + $\left(\frac{1}{m} W \times 2240\right)$

On Prussian railways, R is taken at $\frac{1}{100}$ W = 22·4 lbs. per ton.

By experiment in railway goods stations, R = 30 lbs. per ton moving slowly.

A train of 300 tons total can be hauled 40 miles per hour on a level with 600 I.H.P. (*F. W. Dean*). This gives a resistance of 18·75 lbs. per ton, assuming E.H.P. = I.H.P.

### 570. Locomotive Express Engines.

Inside cylinder engine, 17 inches diameter, 24 inches stroke, firegrate 15 sq. feet area, heating surface, firebox 89 sq. feet, tubes 1013 sq. feet. Load on axles, 9·45 tons leading, 11 tons driving, 8·75 tons trailing. Total wheel base 15 feet 8 inches. Can draw 293 tons on a level, at 45 miles per hour, with 120 lbs. per sq. inch. Leading wheels 3 feet 7½ inches diameter, driving and trailing coupled 6 feet 7½ inches diameter. Coal 26·3 lbs. per mile, with 10 coaches. —*L. & N. W. Railway.*

### 571. Effect of Speeds and Gradients.

An engine of uniform power will pull

| | | | |
|---|---|---|---|
| 40 | vehicles at | 20 | miles per hour. |
| 30 | ,, | 30 | ,, |
| 21 | ,, | 40 | ,, |
| 15 | ,, | 50 | ,, |
| 11 | ,, | 60 | ,, |

and running at 15 miles per hour will pull

| | | | |
|---|---|---|---|
| 42 | vehicles | on a level | |
| 34 | ,, | up 1 in | 600 |
| 27 | ,, | ,, | 300 |
| 20 | ,, | ,, | 150 |
| 15 | ,, | ,, | 100 |
| 12 | ,, | ,, | 75 |
| 9 | ,, | ,, | 50 |

—*Du Bosquet.*

### 572. Railway Curves.

W = maximum rigid wheel base of rolling stock in feet.
G = gauge of railway, i.e. inside measurement between rails in feet.
R = minimum radius of curve in feet.

$$R = 9\,W\,G.$$

*Examples* :—

Coal wagon, wheel base 8 feet 6 inches, gauge 4 feet $8\frac{1}{2}$ inches, wheels 3 feet diameter, radius of curve = 360 feet = $5\frac{1}{2}$ chains radius.

Four-wheel-coupled tank locomotive, wheel base 3 feet 6 inches, gauge 2 feet, wheels 1 foot 6 inches diameter, radius of curve = say 60 feet radius.

### 573. Air Condensers.

Steam passed through thin brass tubes, air circulated by fan outside. With $\frac{3}{4}$ inch inside diameter of tubes, 5-feet run = 1 sq. foot cooling surface. Weight of condenser, say 1 ton per 800 sq. feet cooling surface. Difference of temperature of air at entrance and exit say 80° F. May be used for producing blast after leaving condenser. Loss of heat by $\frac{3}{4}$-inch pipe for air contact only = 2·25 units of heat per sq. foot per hour per 1° F. difference of inside and outside. At 212° F. 1 lb. of steam contains 966 units of latent heat which are given up on condensation.

*Example* :—Steam 212°, air mean 100°, difference 112°, $112 \times 2{\cdot}25 = 252$ units passing per sq. foot per hour. $\frac{252}{966} = {\cdot}26$, say $\frac{1}{4}$ lb. steam may be condensed per sq. foot per hour. Experiments on single pipes give much higher efficiency, but this is probably on account of radiation playing a more important part. By an article in 'Engineering' (1869) $\frac{1}{3}$ lb. may be taken.

At a consumption of 30 lbs. steam per H.P. per hour, and an estimate of $\frac{1}{4}$ lb. condensed per sq. foot per hour, cooling surface = 120 sq. feet per H.P. And for 80° F. difference of air temperatures we have weight of air required per lb. of steam =

$$\frac{\text{Units of heat to be absorbed by air}}{\left.\begin{matrix}\text{Diff. of entrance and}\\ \text{exit, F}^\circ\end{matrix}\right\} \times \left\{\begin{matrix}\text{specific heat of air at}\\ \text{constant pressure}\end{matrix}\right.}$$

$$= \frac{U}{(T - t) \cdot 238} = \frac{966}{80 \times \cdot 238} = 50 \text{ lbs., and}$$

$50 \times 30$ lbs. steam per H.P. = 1500 lbs. air per H.P. At $\frac{1}{10}$ lb. as the weight of a cubic foot of air we require $1500 \times 10 =$ 15,000 cubic feet air per H.P. per hour.

If boiler evaporates 5 lbs. per sq. foot heating surface per hour, then cooling surface must equal 20 times heating surface.

When temperature of air = 59° F., copper will condense about 0·28 and cast iron 0·36 lbs. steam per sq. foot per hour.

## 574. Gas Engines.

The Otto cycle of working :—

First revolution $\left\{\begin{array}{l}\text{Outstroke draws in air and gas.}\\ \text{Instroke compresses charge.}\end{array}\right.$

Second revolution $\left\{\begin{array}{l}\text{Outstroke caused by the explosion.}\\ \text{Instroke discharges burnt products.}\end{array}\right.$

# SECTION XII.

# HYDRAULIC MACHINERY.*

## 575. Summary of Hydraulics.

The quantities discharged from different apertures of similar character vary directly as the areas, and as $\sqrt{\text{altitudes}}$.

On account of friction, a small orifice discharges proportionally less water; and of several orifices having the same area, that with the smallest perimeter discharges most: hence a circular orifice is most advantageous.

Water issuing from a sharp-edged circular aperture is contracted at distance of ½ diameter from orifice, from 1 to . . . . . { Bossut ·666, Venturi ·631, Eytelwein ·64 } in area, called "vena contracta." Vein contracts more with greater head, therefore discharge slightly diminished below theoretical discharge due to altitude. When the orifice is not sharp-edged, the contraction is partially suppressed and the flow increased.

Water flowing from pipe of sectional area A into one of less sectional area $a$, will have a coefficient of contraction

$$= \frac{1}{\sqrt{\left(2\cdot618 - 1\cdot618\,\frac{a^2}{A^2}\right)}}$$

—*Rankine.*

$= \cdot618$ when A is infinite, say a large tank.

* See lecture by the author on 'Hydraulic Machinery, Past and Present,' read before the Railway Officials' Association in 1880. Demy 8vo, 42 pp., and folding plate of illustrations (Spon, 1*s.*).

The discharge through a tube of diameter = length is the same as through simple orifice of equal diameter. The discharge increases up to a length of 4 diameters.

The discharges through horizontal conduit pipes are directly as the altitudes and inversely as $\sqrt{\text{length}}$. To have perceptible and continuous discharge, head must not be less than $\frac{\text{length}}{1300}$. Vertical bends discharge less water than horizontal, and horizontal bends less than straight pipes.

Right angle bends 1 foot radius, with a flow of 32 feet per second, lose approximately 1 foot head, or for any other flow, say $\cdot 001\ v^2$.

The discharge through pipes varies approximately as diameter$^2$.

In prismatic vessels twice as much is discharged from the same orifice if the vessel be kept full, during the time it would take to empty itself.

### 576. Torricelli's Theorem.

Particles of fluid escaping from an orifice possess the same velocity as if they had fallen freely *in vacuo* from a height equal to that of the fluid surface above the centre of the orifice.

### 577. Pressure of Water.

Water transmits pressure equally in all directions (Pascal), and its own weight acts as additional pressure in proportion to the depth from surface. Pressure is perpendicular to containing surface. Water is only compressible to a very small extent. Pressure per unit of area is affected solely by depth, and is entirely independent of extent of surface.

Area of any portion of containing surface in sq. feet × distance of its centre of gravity in feet from surface of liquid × weight of liquid per cubic foot = pressure upon that portion of containing surface.

The "centre of pressure" on a plane surface, or point

where pressures would be balanced by a resistance, is $\frac{1}{3}$ height, or $\frac{2}{3}$ down from surface.

The pressure of the air is not able to sustain a column of water more than 34 feet high, hence water cannot by any possibility be raised by direct suction from a greater depth —the exact amount varies with the barometric pressure and the method employed.

If pressure be applied to a liquid entirely filling a closed vessel, that pressure will be transmitted equally to all parts of the liquid.

### 578. Floatation Power of Water.

When a solid body floats on a liquid, the weight of the liquid displaced is equal to the weight of the body.

When a heavy body is immersed in water, it displaces an equal bulk, and loses weight equal to the weight of water displaced.

$$\text{Specific gravity} = \frac{\text{weight of body in air}}{\text{weight of equal bulk of water}},$$

or

$$= \frac{\text{weight of body in air}}{\text{weight in air} - \text{weight in water}}.$$

Solid cast iron loses $14\frac{1}{4}$ per cent. of its weight when immersed in water.

### 579. Hydrostatic Paradox.

"Any quantity of fluid, however small, may be made to balance and support any quantity or weight, however great."

Thus the water in a 3-inch pipe from a tank on the top of a building may support a load of many cwts. in the cradle of a hoist.

### 580. Principle of Archimedes.

When a body is immersed in water it loses weight, and the loss of weight is equal to the weight of the water displaced by the body.

## 581. Pascal's Principle.

"If a vessel full of water, closed on all sides, has two openings, the one a hundred times as large as the other, and if each be supplied with a piston which fits exactly, a man pushing the small piston will exert a force which will equilibrate that of a hundred men pushing the piston which is a hundred times as large, and will overcome that of ninety-nine. And whatever may be the proportion of these openings, if the forces applied to the pistons are to each other as the openings, they will be in equilibrium."

—*Blaise Pascal's 'Equilibrium of Liquids.'*

## 582. Compressibility of Water.

Water is popularly supposed to be incompressible, but "If the water of the ocean were to suddenly cease being compressible, the result would be that 4 per cent. of the habitable land on the globe would be submerged, because the mean depth of water would be raised by 116 feet."

—*Prof. Tait.*

## 583. Comparison of Discharge through various Apertures.

Theoretical velocity in feet per second

$$= \sqrt{\text{head in feet} \times 2\,g}.$$

Theoretical discharge being 1,
Short tube projecting into reservoir = ·5.
Orifice in thin plate, 1 in. diameter = ·62.
Tube 2 diameters long = ·82.
Conical tube approaching form of contracted vein = ·92.
" " edges rounded off = ·98.

Or, say theoretical velocity ft. per second = $8 \cdot 04 \sqrt{\text{head ft.}}$

| | |
|---|---|
| Effective velocity through orifices of the form of vena contracta, well-placed sluices, large bridge openings, &c. . . . . | $= 7 \cdot 5 \sqrt{h}.$ |
| „ large vertical pipes and narrow bridge openings . . . | $= 6 \cdot 75 \sqrt{h}.$ |
| „ sluices without side walls, dock gates, and mill stream sluices | $= 5 \sqrt{h}.$ |

## 584. Practical Discharge of Water.

$h$ = head in feet.
$c$ = discharge in cubic feet per minute.
$a$ = area in square feet.

$$k = \text{constant} = \begin{cases} 450 \text{ for bridges, \&c.} \\ 400 \text{ „ pipes, \&c.} \\ 300 \text{ „ ordinary sluices.} \end{cases}$$

$$c = k\,a \sqrt{h}, \quad h = \left(\frac{c}{k\,a}\right)^2, \quad a = \frac{c}{k \sqrt{h}}.$$

—*Beardmore.*

When the outlet is "drowned" the head will be the difference in level between water over inlet and outlet.

## 585. Weight and Bulk of Water.

A standard or imperial gallon of water was formerly 277·274 cubic inches, is now 10 lbs. avoirdupois at 62° F. and 30″ bar. = 277·123 cubic inches, or ·160372 cubic feet.

—*Capt. E. M. Shaw.*

A cubic foot of pure water at its point of maximum density, 39° F. [39·1° F., or 4° C.], weighs 998·8 ounces = 62·425 lbs. —*Twisden.*

Standard weight of water = 62·321 lbs. per cubic foot.

—*Sale of Gas Act*, 1859.

The experiments of the Standards Office of the Board of Trade show that a cubic inch of water weighs 252·286 grains instead of 252·458 grains, of which 5760 go to the pound Troy, and 7000 to the pound Avoirdupois, therefore a gallon of water now equals 277·463 cubic inches.

—'*The Engineer*,' 1889.

U.S. standard gallon weighs $8\frac{1}{2}$ lbs., and contains 231 cubic inches.

A cubic foot of average sea water weighs 64 lbs.

A cubic foot of ice at 32° F. is 5 lbs. lighter than a cubic foot of water at same temperature.

Water in freezing expands $\frac{1}{9}$ of its bulk.

| Weight per Cubic Foot. | | lbs. |
|---|---|---|
| Ice | . . . . . . . . | 58·078 |
| Water, maximum density | $39\frac{1}{5}$° F. | 62·4491 |
| ,, ,, | 60° F. | 62·39 |
| ,, ,, | 212° F. | 59·745 |
| ,, average, say | . . . . | 62·4 |

—*Spon's Dictionary.*

### 586. Useful Numbers in connection with Water.

Cubic feet × 6·232, say $6\frac{1}{4}$ = gallons.
Cubic feet per minute × 9000 = gallons per 24 hours.
Head in feet × ·434 = lbs. per sq. inch.
Lbs. per sq. inch × 2·3 = feet-head.
Tons × 224 = gallons.
Diameter inches² ÷ 10 = gallons per yard.
Weight of sea water = 1·027 weight of fresh water.
168 gallons = 21 bushels = 27 cubic feet = 1 cubic yard.

### 587. Velocities of Streams.

$s$ = surface velocity centre of stream.
$b$ = bottom ,, ,,
$m$ = mean velocity of whole stream.

$$b = (\sqrt{s} - 1)^2, \quad m = \cdot 8\,\frac{s + b}{2}, \quad \text{or} \quad m = \cdot 8\,(s - \sqrt{s} + \cdot 5).$$

—*Du Buat.*

$$m = \cdot 705\,s + \cdot 001\,s^2. \qquad \text{—von Wagner.}$$

$$m = s + 2\cdot 5 - \sqrt{5\,s}. \qquad \text{—Beardmore.}$$

$$m = \cdot 835\,s. \qquad \text{—Neville.}$$

$$m = \tfrac{2}{3}\,s. \qquad \text{—Adams.}$$

$$m = \cdot 653\,s. \qquad \text{—Baumgarten.}$$

$$m = \frac{s\,(s + 7\cdot 783)}{s + 10\cdot 345}. \qquad \text{—Prony.}$$

Velocities may be feet per minute, or inches per second, &c.

Inches per second $\times$ 5 = feet per minute.

### 588. Discharge over Weirs.

$h$ = true head from sill to still surface in feet.
$c$ = discharge in cubic feet per minute per foot width.

$$c = 214\,\sqrt{h^3}.$$

When the water passes the point where the constant head begins to deflect, with an appreciable initial velocity = $v$ feet per second,

$$c = 214\,\sqrt{h^3 + \cdot 035\,v^2\,h^2}.$$

For small weirs:

$l$ = length of weir or notch in inches.
$g$ = gallons discharged per minute.
$d$ = depth of head in inches.

$$g = 2\,l\,\sqrt{d^3}.$$

### 589. Discharge over Weirs per Foot Width.

$h$ = height of flow on edge of rule over square notch or edge of horizontal weir.
$c$ = cubic feet per minute.

| | | | |
|---|---|---|---|
| $h$ = 1 | inch, then | $c$ = | 5·10 |
| $1\frac{1}{4}$ | „ | „ | 7·14 |
| $1\frac{1}{2}$ | „ | „ | 9·23 |
| $1\frac{3}{4}$ | „ | „ | 11·78 |
| 2 | „ | „ | 14·43 |

—*Hawksley.*

590. Flow of Water through Rectangular Notch.

$Q$ = cubic feet per second.
$b$ = breadth of notch.
$h$ = height of surface of still water above bottom of notch.
$c$ = a coefficient of discharge.
$B$ = breadth of weir.

$$Q = \tfrac{2}{3} c \,.\, b\, h \,.\, \sqrt{2\, g\, h} = 5{\cdot}35\, c\, b\, h\, \sqrt{h}.$$

If $b = \frac{1}{4}$ width of weir (the minimum advisable), $c = {\cdot}595$
" " whole width of weir . . . . . . . . $c = {\cdot}667$

For any intermediate proportions $c = {\cdot}57 + \dfrac{b}{10\,B}$.

—*Cotterill's App. Mech.*

591. Flow of Water through Triangular Notch.

$$Q = \frac{8}{15} c \,.\, \frac{b\, h}{2} \,.\, \sqrt{2\, g\, h}.$$

When $b = 2\,h$, $c = {\cdot}595$, $Q = 2{\cdot}54\, h^{\frac{5}{2}}$.
" $b = 4\,h$, $c = {\cdot}620$, $Q = 5{\cdot}3\, h^{\frac{5}{2}}$,

—*Cotterill's App. Mech.*

592. Rivers, Sewers, Drains, &c.

$D$ = hydraulic mean depth in feet

of streams or pipes partly full $= \dfrac{\text{sectional area}}{\text{wetted perimeter}}$,

of pipes running full or half full only $= \dfrac{\text{diameter}}{4}$.

$f$ = fall in feet per mile.
$M$ = mean velocity in feet per minute.
$d$ = diameter of pipe in feet.

$l$ = length in feet.
$h$ = head or fall in feet.
$c$ = cubic feet per minute.

I = mean hydraulic inclination $= \frac{l}{h}$.

$$M = \sqrt{D \times 2f} \times 55, \quad c = aM.$$

—*Beardmore.*

$$M = \frac{6000 \sqrt{D}}{\sqrt{I}}.$$

—*Leslie.*

$$c = \frac{2356 \sqrt{d^5}}{\sqrt{I}}.$$

—*Eytelwein.*

$$M = 92 \cdot 26 \sqrt{I D}.$$

## 593. Natural Evaporation of Water.

Mean evaporation of water from open surface in London, large body of water 21 inches per annum, small body 50 inches; rainfall during same period 25 inches.

## 594. Efficiency of Hydraulic Water-raising Machines.

| | | | |
|---|---|---|---|
| Hydraulic ram | | | ·75 |
| Turbines and pumps | | | ·60 |
| Overshot waterwheel and pumps | | | ·55 |
| Poncelet | ,, | ,, | ·45 |
| Breast | ,, | ,, | ·44 |
| Undershot | ,, | ,, | ·28 |

—*G. H. Hughes.*

## 595. Waterwheels.

*Undershot Wheel.*—Float boards radial, or inclined 20° towards current when not used in tidal stream. Breadth may equal or exceed diameter. Maximum efficiency when velocity of wheel equals half velocity of stream.

*Breast Wheel.*—Floats shrouded or covered at the sides and curved to form buckets. Breastwork of masonry built up round wheel as high as centre line. Stream led down a masonry slope to act on wheel by momentum and gravity. Suited for moderate supply of water and fall of 6 or 8 feet.

*Overshot Wheel.*—Floats formed into buckets. Water led in trough to top of wheel. Ratio of width to diameter usually small. Requires less water to drive it than the other forms, and is more than twice the power of an undershot wheel of same size. Fall must not be less than diameter of wheel. Smeaton found that in ordinary wheels the velocity of circumference should not exceed 3 feet per second.

*Poncelet Waterwheel.*—Undershot, floats curved to meet stream, maximum effect when velocity of stream equals $2\frac{1}{2}$ times velocity of wheel. Modulus = ·7.

## 596. Turbines.

*Fourneyron's* (1827).—Water admitted in centre of wheel, passing along curved guides, and discharged at circumference against guides curved in opposite direction.

*Thompson's Vortex Wheel.*—Water admitted at circumference and discharged at centre, can be fixed above tail-race up to 30 feet, power being obtained by suction.

*Fontaine's and Jonval's Parallel Flow Wheels.*—Water admitted above through fixed inclined vanes and discharged below, axis vertical, inclined vanes on wheel with angle reversed.

## 597. Hydraulic Ram.

Where a fall of water of not less than 2 feet can be obtained through an inclined supply pipe, the hydraulic ram may be used for raising water to a considerable height, say 150 feet, without the intervention of other machinery. The action is as follows:—The water passing through the drive

pipe (supply or injection pipe) gradually increases in velocity until it suddenly closes the pulse valve through which it is escaping, when a small quantity is forced by the momentum of the bulk through the delivery valve into the air vessel, and thence into the delivery pipe or rising main. The escape valve being then relieved, the supply water again flows through until its velocity is sufficient to close the valve. This alternate motion is repeated as long as the conditions remain unaltered. The pulsations vary from 30 to 100 per minute, according to the fall of water.

Average proportions and results are:

$D$ = diameter of fall pipe in inches.
$f$ = fall in feet.
$d$ = diameter of rising main in inches.
$h$ = head of ditto in feet.
$G$ = gallons per minute to work ram.
$g$ = gallons raised in 24 hours.

$h$ does not generally exceed $50\,f$.

$$d = \tfrac{1}{2}\,D.$$

$$G = 3\,D^2.$$

$$g = 3000\,D^2\,\frac{f}{h}.$$

598. CENTRIFUGAL PUMPS.

Power required to drive them varies as the 1·5 power of the lift.

$a$ = gallons lifted per minute.
$H$ = lift in feet.

$$\text{I.H.P.} = \frac{10\,a \times H^{1\cdot5}}{2 \times 33{,}000}.$$

Speed at periphery $= 8\,\sqrt{H}$ = feet per second.

—*A. Hanssen.*

*Note.*—$H^{1\cdot5} = H^{\frac{3}{2}} = \sqrt{H^3}$.

599. Discharge through Pipes from Natural Head.

| — | d. | c. | d. | c. |
|---|---|---|---|---|
| H = head of water in feet . . . . | 1 | 4·71 | 7 | 612·32 |
| L = length of pipe in feet . . . . | $1\frac{1}{4}$ | 8·48 | 8 | 854·99 |
| $d$ = diameter of pipe in inches . . . | $1\frac{1}{2}$ | 13·02 | 9 | 1147·61 |
| $c$ = constant (see table) . . . . | 2 | 26·69 | 10 | 1493·47 |
| W = cubic feet discharged per minute . | $2\frac{1}{2}$ | 46·67 | 12 | 2356·00 |
| $W = \dfrac{c}{\sqrt{\dfrac{L}{H}}}$. | 3 | 73·50 | 15 | 4115·93 |
| | 4 | 151·02 | 18 | 6493·14 |
| | 5 | 263·87 | 24 | 13328·0 |
| | 6 | 416·54 | 30 | 23282·0 |

—*Beardmore.*

$$W = 4{\cdot}71 \sqrt{\frac{d^5 H}{L}}, \quad d = {\cdot}538 \sqrt[5]{\frac{L W^2}{H}}.$$

—*Eytelwein.*

G = gallons delivered per hour.

$$d = \tfrac{1}{15} \sqrt[5]{\frac{G^2 \frac{L}{3}}{H}}, \qquad G = \sqrt{\frac{(15\,D)^5 H}{\frac{L}{3}}}.$$

—*Hawksley.*

$r$ = hydraulic mean depth in feet.

$s$ = sine of inclination $= \dfrac{\text{total fall}}{\text{total length}}$.

$v$ = velocity feet per second.

$v = 140 \sqrt{r s} - 11 \sqrt[3]{r s}, \quad W = 47{\cdot}124\, d^2 v.$

—*Neville.*

Q = discharge cubic feet per second.

R = hydraulic radius in feet.

A = area of pipe in sq. feet.

S = hydraulic gradient in terms of the line of slope.

N = coefficient of roughness of internal surface of pipe and other irregularities, say ·013.

$$Q = \frac{V\,R}{N}\left\{\frac{M + 1\cdot811}{M + V\,R}\right\} A \sqrt{R\,S}.$$

$$M = N\left\{41\cdot6 + \frac{\cdot00281}{5}\right\}.$$

—*Kutter.*

This is for the calculation of mains as ordinarily laid.

### 600. Friction of Water in Pipes.

$h$ = head in feet, $d$ = diameter in inches.
$l$ = length in feet, $v$ = velocity in feet per second.

$$\text{Effective head} = \frac{4}{5}\;\frac{h}{\dfrac{l}{50} + d},$$

or allow $\frac{1}{3}$ to $\frac{1}{4}$ more diameter than is theoretically required for the quantity. —*Bird and Brooke.*

10 to 12 feet head is absorbed in friction per mile of pipe. —*Bateman.*

L = length in miles.
V = velocity in feet per second.
D = diameter of pipe in feet.
H = loss of head in feet by friction.

$$H = \frac{2\cdot25\,L\,V^2}{D}.$$

—*Boulton and Watt.*

### 601. Water Supply.

To find supply by given head through given lengths of various size pipes, assume a probable flow, then find the head necessary to produce the velocity in the smallest pipe $= \frac{G^2}{215\,d^4}$. Then add the head necessary to overcome friction in each length of pipe separately by the formula $= \frac{G^2\,L}{240\,d^5}$,

where G = gallons per minute, L = length yards, $d$ = diameter inches. If the total found thus does not agree with the given head, the true discharge will be the assumed discharge × sq. root of true head ÷ sq. root of head found above. This is without allowing for bends. If delivering at a jet, the diameter of jet must be taken in first formula. The probable height of a jet

$$= \text{head to produce velocity} - \frac{(\text{head to produce velocity})^2}{80 \text{ times diameter of jet in } \frac{1}{8}\text{ths}}.$$

### 602. Tests of Metal for Pipes.

The American Waterworks Association recommends test bars for proving the quality of metal for pipes to be 26 inches long, 2 inches wide, 1 inch thick, loaded in centre between supports 24 inches apart, to have a deflection of not less than ·25 inches before breaking, a transverse strength of 1900 lbs., and tensile strength of 20,500 lbs. The pipes to be sounded with a 3-lb. hammer while under test pressure of 300 lbs. per sq. in.

Socket-pipes should be cast at an angle of not less than 5° from the horizontal for every inch diameter, and always socket end downwards. When specified to be cast on end, or cast vertically, an angle of 30° is sometimes claimed as sufficient.

See also Art. 132.

### 603. Size of Water Companies' Mains.

Water companies' mains are generally calculated for a velocity of 2 to 3 feet per second, with a minimum diameter of 3 inches.

### 604. Freezing of Water.

Water at 39·1° F. is at its point of maximum density. The specific gravity of ice (pure distilled water at 39·1° F. being 1) is ·865, therefore, on conversion to ice, water expands

$\frac{1\cdot000}{\cdot865}$ of its bulk $= 1\cdot156$ times. In pipes containing freezing water the expansion of the ice during solidification may be taken as transverse; and, if no leakage—or compression of locked-in air—takes place, the diameter must increase by $\sqrt{1\cdot156} = \frac{75}{1000}$. This would be roughly equivalent to a stretch 75 times greater than that at the elastic limit, so that no pipe could withstand the effect of freezing when completely filled with water.

In England a depth of 2 feet 6 inches from the surface of the ground to top of pipe is usually sufficient to prevent freezing. Where the water may remain quiescent for 24 hours, 3 feet is necessary.

### 605. Delivery of Water in Pipes.

$v$ = velocity in feet per second through pipe.
$a$ = area of pipe in sq. inches.
$d$ = diameter of pipes in inches.
W = discharge in cubic feet per minute.

$$W = \frac{v\,a}{2\cdot4}, \qquad v = \frac{2\cdot4\,W}{a}, \qquad a = \frac{2\cdot4\,W}{v}.$$

Approximately:

$$W = \frac{v\,d^2}{3}. \qquad v = \frac{3\,W}{d^2}. \qquad d = \sqrt{\frac{3\,W}{v}}.$$

### 605a. Velocity of Water through Pipes and Valves.

With an Accumulator pressure of 700 lbs. per sq. inch, the natural velocity (theoretical) is $322\cdot32$ feet per second. It is found in practice that not more than $\frac{1}{10}$th of this can be obtained through the pipes and $\frac{1}{3}$rd through the valves, in order to maintain the proper speed for the machinery. The loss from friction in the pipes is about 1 lb. per sq. inch

per 100 feet length, after they have been laid some time; 1 lb. additional for each bend, and 10 lbs. each branch.

In order to allow for the furring-up of the small pipes, it is not safe to reckon upon more than three times the diameter of pipe in inches as the velocity obtainable in feet per second. It is also usual to calculate the velocity through the valves at not more than 98 feet per second.

### 606. Mechanical Value of Fluids under Pressure.

U = units of useful work in foot-lbs.
$p$ = pressure in lbs. per sq. inch.
Q = quantity used in cubic feet.
M = modulus of machine, or coefficient of effect found by experiment, and varying with class of machine or arrangement.

$$U = 144 \, p \, Q \, M.$$

### 607. Mechanical Value of Water under Accumulator Pressure.

Theoretically the mechanical value of water under accumulator pressure of 700 lbs. per sq. inch (549·78, say 550 lbs. per circular inch) is 100,800 foot-lbs., or 45 foot-tons per cubic foot of water, irrespective of the time in which it is consumed; or 3·0545 H.P. per cubic foot per minute; or 1 H.P. requires ·32738 cubic feet per minute.

Approximately this equals 1 H.P. from 2 gallons of water per minute; but practically, allowing for all losses, about $3\frac{1}{2}$ gallons are required; or 4 cubic feet (= 25 gallons) will give out 100 foot-tons in work.

Theoretically 1 gallon = 7·2 foot-tons of work, practically 10 gallons will lift 1 ton to a height of 40 feet at a cost of one penny. If cradle, cage, bucket, or tub be used, the weight must be included and the efficiency will be thereby reduced.

### 608. Power required to work Hydraulic Machinery.

In hotels, wharves, &c., with several machines, allowance must be made for $\frac{2}{3}$ of the machinery working to half the full height every $1\frac{1}{2}$ minutes.

$\therefore$ power per minute = $\frac{2}{9}$ total capacity of machinery.

At wharf with several cranes, $\frac{2}{3}$ machinery full lift, every $1\frac{1}{2}$ minute.

$\therefore$ power per minute = $\frac{4}{9}$ capacity of machinery.

At railway goods stations, docks, &c., where many machines are idle at one time, say $\frac{1}{8}$ machinery full height every $1\frac{1}{2}$ minute.

$\therefore$ power = $\frac{1}{12}$ capacity of machinery.

At small wharves where cranes are rapidly worked, all machinery, full height every $1\frac{1}{2}$ minute.

$\therefore$ power = $\frac{2}{3}$ capacity of machinery.

### 609. Hydraulic Pressure Accumulator,

invented by Lord Armstrong in 1850, consists of vertical cylinder and ram, to the crosshead of which a load of 20 to 120 tons is hung to create the pressure necessary for working the machinery, obviating the use of a high tower giving a natural head of water.

The load is usually contained in a cylindrical casing. Clean washed heavy Thames ballast, weighing 27 cwt. per cubic yard, is the cheapest and best procurable in London. Where convenient, railway ballast may be used. Iron slag is sometimes used; it has the advantage of weight, and therefore occupies less space, but is expensive and very awkward to handle. Copper ore slag is not suitable, owing to the galvanic action set up. Water has been used for ballast where the pressure is required to be varied occasionally. Clay has also been used in its natural state, but is

better when burnt. Iron kentledge, brickwork, cast-iron blocks and direct steam pressure have also been used by various manufacturers for producing the load.

The accumulator is a limited reservoir of power enabling the steam engine to work at the average speed requisite to supply machinery working intermittently. The capacity is equal to the possible excess of water required by the machinery over that supplied by the engine, in a given time.

### 610. Pressure in Pipe-Mains.

Working pressure averages 700 lbs. per sq. inch when given by accumulator, but may be from 350 to 1000 lbs.

700 lbs. per sq. inch = 549·78 lbs. per circular inch, equivalent to 1613·2 feet head.

All pipes subject to the accumulator pressure to be tested to 2500 lbs. per sq. inch before leaving the works, and to 2000 lbs. per sq. inch after being laid.

Water companies' pipes to be tested with a pressure equal to 500 feet head, and while under pressure to be sounded from end to end with a 5-lb. hammer.

Pressure in water companies' mains is at maximum between 2 and 3 A.M., minimum 6 A.M. to 6 P.M., variation, say from 10 to 60 lbs. per sq. inch.

### 611. Variation of Accumulator Pressure due to Working of Machinery.

Normal pressure, say 700 lbs. per sq. inch. Average variation from 50 lbs. below to 100 lbs. above the normal pressure. Maximum variation 250 lbs. above and below, but this only occurs on a long line of pipe where the accumulator is at some distance from the machine.

### 612. Friction of Accumulators.

$P$ = pressure in lbs. per sq. inch taken at half stroke, accumulator rising slowly.

$p$ = pressure in lbs. per sq. inch, accumulator falling slowly.

$d$ = diameter in inches.

$f$ = friction of ram in lbs. per sq. inch.

$$f = \frac{P - p}{2}.$$

At the Marseilles Docks the friction of a 17-inch accumulator amounted to 7·355 lbs. per sq. inch, or not quite 1 per cent. of the gross load. —*Hawthorn.*

At Scottish Wharf the friction of a 17-inch accumulator was 10 lbs. per sq. inch.

From experiments at Liverpool and Birkenhead, the difference of pressure with the accumulator rising or falling was about 30 lbs. per sq. inch, or 15 lbs. for the single friction.

Generally,

$$f = \frac{170}{d}.$$

### 613. Friction of Cup Leathers.

Depth of leather, or length of ram exposed to pressure sideways, makes no difference. Friction increases as the pressure increases. Friction of leathers, under same pressure, of different diameters, increases in direct proportion with the diameters, or with the square root of the respective gross loads.

$d$ = diameter. $p$ = lbs. per sq. inch.

Gross friction in lbs. = $\cdot 0315\, d\, p$.

—*John Hick.*

### 614. Air Accumulators.

W = working capacity in cubic feet of water.
C = mean capacity for air in cubic feet.
$a$ = cubic feet air required at atmospheric pressure to charge accumulator.
$p$ = mean pressure in lbs. per sq. inch.
P = maximum " "
P′ = minimum " "

$$P = \frac{p}{1 - \frac{W}{2C}}. \qquad P' = \frac{p}{1 + \frac{W}{2C}}.$$

$$C = \frac{P'W}{2(p - P')}. \qquad a = C\frac{p}{15}.$$

May be proportioned as follows:

D = inside diameter in feet.
L = inside length in feet.

$$D = \sqrt{\cdot 4244\,W}. \qquad L = 11\,D. \qquad C = 3\,W.$$

Total capacity divided thus:

| | |
|---|---|
| Air under maximum pressure . . | $= \frac{15}{22}$ |
| Water " " . . | $= \frac{6}{22}$ |
| Margin from level of outlet to lowest water-level . . . . . | $= \frac{1}{22}$ |

If $p = 700$, then $P = 840$, and $P' = 600$.

### 615. Speed of Pumping

depends entirely upon circumstances and provision made to resist shocks. Ordinary direct-acting pumping engines will run against accumulator pressure of 700 lbs. per sq. inch at a piston speed of 200 feet per minute without knocking. Large pumping engines lifting from wells run slower, and small pumps quicker.

### 616. Atmospheric Pressure.

30 inches mercury = 34 feet water; so that pumps cannot draw by suction deeper than 34 feet, whatever be the arrangement of the mechanism; 27 or 28 feet is a usual maximum.

### 617. Efficiency of Pumps and Accumulator.

R = any number of revolutions of engine.
$r$ = rise of accumulator in inches for same number of revolutions.
D = diameter of accumulator ram in inches.
$d$ = diameter of pump in inches (piston if double-acting, ram if single-acting).
$s$ = stroke of pump in inches.
$n$ = number of pumps.

$$\text{Efficiency} = \frac{D^2 r}{d^2 s n R}.$$

$$\left.\begin{array}{l}\text{Loss per cent. of working}\\ \quad\text{capacity of pumps}\end{array}\right\} = \frac{100\,\{(d^2 s n R) - (D^2 - r)\}}{d^2 s n R}.$$

When all parts are in good order the loss in the pumps averages 5 per cent.

### 618. Coefficient of Steam Engine.

*Example.*—Horizontal high-pressure direct-acting pumping engine working against accumulator pressure of 700 lbs. per sq. inch, specified as 84 H.P. at 60 revolutions per minute. Two steam cylinders each 16 inches diameter × 20 inches stroke; 2 double-acting force pumps with piston, each 5·1 inches diameter = $\frac{1}{10}$ area of steam piston, and ram 3·6 inches diameter = $\frac{1}{2}$ area of pump. Boiler pressure 60 lbs. per sq. inch by gauge. Cut-off $\frac{2}{3}$ stroke. Mean pressure by calculation = 56 lbs. per sq. inch, by indicator diagram 45 lbs. per sq. inch.

16 inches diameter = 201·06 sq. inches area, 5·1 inches diameter = 20·43 sq. inches area, 3·6 inches diameter = 10·18 sq. inches area.

$$\text{Power} = \frac{201 \cdot 06 \times 45 \times 2 \times 120 \times 1\frac{2}{3}}{33,000} = 109 \cdot 67 \text{ I.H.P.}$$

$$\text{Effect} = \frac{20 \cdot 43 \times 700 \times 2 \times 60 \times 1\frac{2}{3}}{33,000} - 5\% \text{ loss} = 82 \cdot 33 \text{ E.H.P.}$$

$$\text{Coefficient} = \frac{82 \cdot 33}{109 \cdot 67} = \cdot 75,$$

or 75 per cent. on the indicated horse-power.

In connection with the above engine the following particulars may be useful:—Fly-wheel 9 feet diameter; two wrought-iron Lancashire boilers, 6 feet diameter × 20 feet long; two flues, each 28 inches diameter, with five Galloway tubes. Double-acting lift pump. Tank, 1500 gallons, for return water. 18-inch accumulator, 23 feet stroke.

In another case the coefficient was found to be as high as ·82, but ·75 is more usual.

### 619. Packing for Force Pumps.

*Cup-leathers* (invented by Bramah) may be single, double, or treble. If single, the open end should be turned towards the delivery end of the pump. If double, they may be back to back, or both turned towards delivery end of pump. If treble, two should be back to back, and the third put as a duplicate to the one turned towards delivery end. In all cases the back of the leather should be closely supported by a washer curved to the shape of the leather. Double leathers back to back are generally used, and last from two days to four months, average say one month. Only the middle of the back of best oil-dressed hide is used.

*Spun-yarn* is sometimes used, the same as for glands of hydraulic machinery generally. It is plaited and formed into rings by splicing, soaked in tallow, and screwed up in a mould to form solid rings of exact size to fit pump.

*Rope* is sometimes used in the same way, being selected of the exact diameter required. The two latter methods are said to last from four to six months, but there is probably more leakage than with leathers.

### 620. Proportions of Hydraulic Pipes.

For accumulator pressure of 700 lbs. per sq. inch:—inside diameter ($d$) in inches $+ 2 =$ thickness of metal in $\frac{1}{8}$ths. Filling pipes made by local firms, $\frac{1}{16}$ inch thicker.

Flanges oval, $2{\cdot}85\, d \times 1{\cdot}55\, d$ and $\frac{1}{2}\, d$ thick, with two square-necked bolts each $\frac{1}{4}\, d$ in diameter for 5-inch pipes and upwards, or $d + 5 =$ diameter in $\frac{1}{8}$ths for 5-inch pipes and under.

Another rule for bolts is $2\,(d + 2) =$ diameter in $\frac{1}{8}$ths.

### 621. Thickness of Pipes for Hydraulic Accumulator Mains.

For 700 lbs. per sq. inch:

Armstrong . . . . $t = \dfrac{d}{8} + {\cdot}25$

Brown . . . . . $t = \dfrac{d}{6}$.

### 622. Thickness of Pipes for Water Co.'s Mains.

H = head of water in feet.
$d$ = diameter of pipe in inches.
$t$ = thickness of metal in inches.
$x$ = 0·37 for pipes less than 12 inches diameter.
0·5 „ from 12 to 30 „ „
0·6 „ „ 30 to 50 „ „
$p$ = working pressure in lbs. per sq. inch.
$r$ = inside radius of pipe in inches.
$c$ = working strength of metal in lbs. per sq. inch.
= 3360 for cast iron, 500 for lead.

For 200 feet head:

Hawksley . $t = {\cdot}18\,\sqrt{d}$.

Unwin . . $t = {\cdot}11\,\sqrt{d} + {\cdot}1$.

Box . . $t = \left(\dfrac{\sqrt{d}}{10} + {\cdot}15\right) + \left(\dfrac{d\,\mathrm{H}}{25000}\right)$,

$$\text{or say} = \frac{\sqrt{d}}{10} + \cdot 15 + \frac{d}{125}.$$

Molesworth . $t = \cdot 000054\,\mathrm{H}\,d + x,$

$$\text{or say} = \cdot 0108\,d + \frac{\sqrt{d}}{10}.$$

Burnell . . $t = \dfrac{p\,r}{c - r}.$

B. Latham . $t = \cdot 2\sqrt{d}.$

Rankine . $t = \dfrac{\mathrm{H}\,d}{12000}$, or $\sqrt{\dfrac{d}{48}}$, whichever is greater, with a minimum of $\frac{3}{8}$ inch.

Trautwine gives as the usual American practice,

$$t = \left\{\left(\frac{p}{\frac{m}{f}} \div 2\right) + 1\right\} \frac{p}{\frac{m}{f}} \times \frac{d}{2},$$

but suggests as an improvement,

$$t = \left\{\left(\frac{p}{\frac{m}{8}} \div 2\right) + 1\right\} \frac{p}{\frac{m}{8}} \times \frac{d}{2} + \cdot 3,$$

where $m$ = cohesion of metal in lbs. per sq. inch, say 16,800.
$f$ = factor of safety, say 6.
$p$ = internal pressure in lbs. per sq. inch.

623. General Rules for Thickness of Cast-Iron Pipes.

Unwin . . $t = \cdot 5\,d\left(\sqrt{\dfrac{2775 + p}{2775 - p}} - 1\right).$

Barlow . $t = \dfrac{\cdot 5\,d}{\dfrac{16000}{p} - 1} \times 5$ for safety.

Adams . . $t = \dfrac{d\,p}{6000} + \dfrac{\sqrt{p}}{100} + \dfrac{\sqrt{d}}{10}$ ($+ \cdot 125$ for steam).

Campin . $t = \dfrac{p\,d}{6000} + \cdot 66.$

## 624. Notes on Pipes.

Iron, composition, and lead pipes are measured by their inside diameter, brass and copper pipes by their outside diameter.

Wrought-iron pipes are bent by filling with sand and making red-hot, keeping the joint on the side of the bend.

## 625. Dr. Angus Smith's Composition for Coating Pipes.

Original recipe was 30 gallons coal tar, 30 lbs. fresh slaked lime, 6 lbs. tallow, 3 lbs. lampblack, $1\frac{1}{2}$ lb. resin; to be well mixed, boiled 20 minutes and put on hot.

The modern practice varies, but a good mixture is $3\frac{1}{2}$ barrels coal tar, $\frac{1}{2}$ barrel coal oil, $\frac{1}{2}$ barrel pitch, with 6 tons gas coke for heating pipes. Made and used as follows:— Into a wrought-iron tank long enough to take a 9-feet pipe, sufficient coal tar to half cover a pipe is put, then pitch beaten to a powder, and sprinkled on the tar, and coal oil poured on the pitch. The pipes heated to 180° to 200°, or as hot as the hand can bear, are put into the liquid separately and turned over and over for 2 or 3 minutes, then placed at an angle to drain, with the lower end clear of the liquid. The above quantities will do about 1000 pieces, bends, branches and straight pipes, or say $\frac{3}{4}$ barrel coal tar to 100 9-feet lengths of 4-inch pipes. This method avoids risk from the liquid catching fire.

## 626. Hydraulic Press with Hand-Pump.

$P$ = pressure in lbs. on handle of pump.
$d$ = diameter of pump in inches.
$l$ = effective leverage $= \dfrac{\text{power leverage}}{\text{resistance leverage}}$.
$D$ = diameter of press in inches.
$M$ = modulus or coefficient of press, say $= \cdot 8$.
$W$ = total load in lbs., or maximum effort of press.

$$W = P\,l\,\frac{D^2}{d^2}\,M.$$

Moseley ('Illustrations of Mechanics,' p. 197) says, "The discovery of it [the hydraulic press] is usually attributed to Pascal; it belongs, however, to the celebrated Stevin, mathematician to the Prince of Nassau, the inventor of decimals."

### 627. Hydraulic Forging Presses.

Hydraulic forging presses capable of exerting a pressure of 1000 to 10,000 tons are used in large works for converting steel ingots into large forgings, &c. They are actuated by a pressure of between 2 and 3 tons per sq. inch to keep down the size of the rams. Smaller presses, exerting say from 25 to 250 tons, are worked at a pressure of 100 atmospheres, or 1500 lbs. per sq. inch.

Ordinary presses are worked from the accumulator pressure of 700 lbs. per sq. inch sometimes with the addition of an intensifier to give the final squeeze.

### 628. Hydraulic Press Cylinders.

$d$ = diameter of ram in inches.
$c$ = clearance between ram and cylinder.
$t$ = thickness of cylinder in inches.
$p$ = pressure in lbs. or tons per sq. inch.
T = maximum tensile strength per sq. inch of material in same units.

$$t = \frac{6\,d\,p}{\mathrm{T}}. \qquad c = \frac{d}{12}.$$

Bottom hemispherical inside and out, except flat part outside to stand on, $= \frac{1}{2}\,d$ in diameter, and joined with easy radius.

Another rule:

P = bursting pressure in tons per sq. inch.
D = outside diameter in inches.
$d$ = inside " "
T = tensile strength tons per sq. inch of material.

$$\mathrm{P} = \mathrm{T}\,\frac{\mathrm{D}^2 - d^2}{\mathrm{D}^2 + d^2}.$$

Another rule :

$p$ = internal bursting pressure, lbs. per sq. inch.
$r$ = inside radius of cylinder in inches.
$s$ = ultimate tensile strength of metal per sq. inch.
say cast iron 18,000 lbs.
„ gun-metal 36,000 lbs.
$t$ = thickness of metal in inches.

$$p = \frac{s\,t}{r + t}. \qquad t = \frac{p\,r}{s - p}. \qquad s = \frac{p\,(r + t)}{t}.$$

—*P. Barlow.*

Common rule:

Thickness of cylinder = radius of bore. This is supposed to be safe at 3 tons per sq. inch working pressure, but is really not safe at more than 2 tons per sq. inch.

Permanent safe working pressure = $\frac{1}{3}$ bursting pressure. Maximum working pressure allowable = $\frac{1}{2}$ bursting pressure. N.B.—A press worked occasionally up to $\frac{2}{3}$ of its bursting pressure, burst after $4\frac{1}{2}$ years' use.

### 629. Effective Pressure for Hydraulic Cranes and Hoists.

$p$ = accumulator pressure in lbs. per sq. inch.
$m$ = ratio of multiplying power.
E = effective pressure in lbs. per sq. inch, including all allowances for friction, but not for weight of moving parts.

$$E = p\,(\cdot 84 - \cdot 02\,m).$$

### 630. Diaphragm Regulator for Hydraulic Machinery.

When a hydraulic crane or hoist works too quickly, and it is desired to reduce the speed to a safe limit, it is usual to partially close the stop valve ; but when there is a risk of this being interfered with, a brass diaphragm, $\frac{1}{8}$th diameter

thick and about $\frac{1}{8}$-inch at edge, is placed in a pipe joint near the working valves. The hole in the diaphragm should be tapered, the small side being next to the machine.

To find size:

$A$ = area of lifting ram, sq. inches.
$m$ = ratio of multiplying power.
$s$ = speed of lifting with full load, feet per second.
$p$ = accumulator pressure, lbs. per sq. inch.
$a$ = area of small side of hole (large side = twice diameter of small side).

$$a = \frac{A\,s}{6\,m\,\sqrt{1 \cdot 932\,p - \cdot 046\,m}}.$$

For direct-acting passenger lifts a diaphragm is always required next to the cylinder.

Umney's rule:

For 700 lbs. per sq. inch,
$D$ = diameter of lifting ram in inches.
$d$ = diameter of hole in inches.

$$d^2 = \frac{D^2\,s}{220\,m}.$$

For other pressures,

$$d^2 = \frac{D^2\,s}{8 \cdot 34\,m\,\sqrt{p}}.$$

631. Power and Speed of Hydraulic Hauling Machines.

| | Strain on Rope. | Hauling Speed, ft. per min. |
|---|---|---|
| Railway capstans . . | 2000 lbs. | 180 |
| | 2240 „ | 200 |
| Barge „ . . | 1½ tons | 120 |
| Ship „ . . | 2½ to 5 tons | 80 |
| Railway traversers. . | 75 lbs. per ton of load. | |
| Lock gate machines . | 375 lbs. per foot width of entrance. | |

### 632. Speed of Lifting with Hydraulic Power.

Warehouse cranes and jiggers 6 feet per second.

Platform cranes and small luggage lifts, 4 feet per second.

Passenger and waggon hoists, 2 feet per second.

Large passenger hoists, over 50 feet lift, first and last 10 feet average 4 feet per second, intermediate height 8 feet per second. At the Blackpool Tower the hoists were designed to lift 325 feet in rather less than 1 minute, say average $5\frac{1}{2}$ feet per second.

Maximum speed under any circumstances, 10 feet per second.

General formula for warehouse cranes:

$W$ = load in tons.

$h$ = height of lift in feet.

$v$ = velocity in feet per second.

$$v = \frac{h}{W + 10}.$$

### 633. Height of Lift for Cranes.

Wool warehouse cranes. Height of lift = net height bottom floor to top floor + 6 feet. Underside of jib head sheave 10 feet 6 inches above level of top floor.

Coal cranes. Minimum height of lift on floating wharf = 40 feet. Height of lift at fixed jetty 50 to 60 feet. Height of lift to riverside hoppers 60 to 80 feet.

### 634. Coal-Weighing Cranes.

To find maximum section of weigh-beam, rectangular bar, single or double.

T = lbs. diagonal thrust on sheave-pin per cwt. of load.

L = effective leverage of thrust in inches, measured perpendicularly to main knife edge.

$C$ = cwts. maximum gross load.
$b$ = breadth, or combined breadth, of weigh-beam in inches.
$d$ = depth of weigh-beam in inches at centre of motion.

$$b\,d^2 = \frac{T\,L\,C}{1000}$$

for a statical factor of safety of $7\frac{1}{2}$ to 1.

### 635. Lifting Rams for Hydraulic Cranes.

$W$ = load to be lifted in lbs.
$w$ = weight of ram, crosshead, sheaves and chain.
$l$ = height of lift in feet.
$m$ = multiplying power.
$c$ = coefficient of effect = $\cdot 84 - \cdot 02\,m$.
$a$ = area of ram in sq. inches.
$s$ = stroke of ram in inches.
$p$ = accumulator pressure in lbs. per sq. inch.
$C$ = capacity of cylinder in cubic feet.

For horizontal cylinders:

$$a = \frac{W\,m}{p\,c}. \qquad C = \frac{W\,l}{144\,p\,c}.$$

For vertical cylinders:

$$a = \frac{W\,m + w}{p\,c}. \qquad C = \frac{W\,l + w\,s}{144\,p\,c}.$$

For inverted cylinders:

$$a = \frac{W\,m - w}{p\,c}. \qquad C = \frac{W\,l - w\,s}{144\,p\,c}.$$

### 636. Turning Rams for Hydraulic Cranes.

$W$ = load in tons.
$R$ = rake in feet.
$l$ = length between bearings in feet.
$d$ = diameter of turning drum in feet.

$p$ = accumulator pressure, lbs. per sq. inch.
$m$ = multiplying power of turning cylinder (usually 2 to 1).
$a$ = area of turning ram in sq. inches.

Alternative formulæ:—

$$a = \frac{120\,W\,R^2\,m}{l\,d\,p}. \qquad a = \frac{3000\,W\,R\,m}{l\,d\,p}.$$

$$a = \left(5906\,\frac{W\,R\,m}{l\,d\,p}\right) - 3\cdot3.$$

### 637. Areas of Valves for Machinery under Accumulator Pressure.

A = area of lifting ram.
$m$ = ratio of multiplying power.
$v$ = velocity of load in feet per second.
V = velocity of water through valve, feet per second.
W = weight of ram, crosshead, sheaves, chain, &c., in lbs.
$a$ = area of lifting valve (mitred spindle).
$a_1$ = area of lowering valve (mitred spindle).

$$a = \frac{A\,v}{m\,V}. \qquad a_1 = \frac{A\,v}{m\sqrt{13\cdot8\,\frac{W}{A}}}.$$

When cylinder is horizontal, then $\frac{W}{700}$ = area of returning ram.

### 638. Areas of Ports in Slide Valves.

$v$ = velocity of load in feet per second.
$m$ = ratio of multiplying power.
A = area of ram in sq. inches.

Area of pressure port $= \frac{A\,v}{98\,m}$ (opening side, V-shaped).

Area of exhaust port $= \frac{1\cdot5\,A\,v}{98\,m}$.

The dimensions of the slide should be such that the unbalanced pressure does not exceed 1000 lbs. per sq. inch on the net working surface of metal.

### 639. Counterweights for Crane Chains.

The overhauling weights should be oval, i.e. egg-shaped, with small end on top to avoid catching under beams, &c. Hole for chain should be $\frac{1}{8}$ inch larger than cross section of links, and interior should be cored out to $\frac{1}{4}$ inch clear all round. The approximate weight of counterbalance required is $\frac{1}{20}$th of the load.

### 640. Stress allowed on Wrought Iron in Hydraulic Cranes.

| | Tons per sq. inch. Tension. | Compression. |
|---|---|---|
| Ballast and coaling cranes . . | $2\frac{1}{2}$ | 1 |
| Warehouse and other cranes lifting from 1 to 5 tons . . . . | 3 | 2 |
| Cranes lifting more than 5 tons . | $3\frac{1}{2}$ | 3 |

### 641. Lock Gates.

The span of a pair of gates should form the diagonal of a square, the curve of the centre line of gates being struck from the opposite corner of the square, radius = length of side = ·707 span, giving angle of 136°, or rise of $\frac{1}{5}$ span.

The pressure of water per sq. foot varies at different depths, being $62 \cdot 5 \times$ difference of head on the two sides at the point considered.

The hauling strain on gate chains averages 336 lbs. per foot width of entrance, but in practice hydraulic and other machines are calculated for an effective strain on the chain of 375 lbs. per foot width of entrance. The total weight of a pair of gates averages $2\frac{1}{2}$ tons per foot width of entrance.

# SECTION XIII.

# ELECTRICAL ENGINEERING.

## 642. The Hypothesis of a Universal Ether.

All space, interatomic as well as interstellar, is filled with a continuous, elastic, perfectly fluid, vibrating medium, in which are propagated light, radiant heat and electricity, as sound is in air. This fluid cannot, however, consist of ordinary matter, as it possesses some of the properties of a solid.

## 643. Comparison of Electricity with other Powers.

Electricity should not be compared to steam or gas, both of which generate and exert a force or power of themselves; but it would be proper to compare electricity with hydraulic, or belt, or rope transmission of power. —*Sandwell.*

## 644. Electric Transmission.

Electric transmission by continuous current may be illustrated by its analogy to hydraulics. The dynamo is essentially a rotary pump, pumping electricity instead of water. In the following sentences the analogous electrical terms are bracketed.

The pump (dynamo) forces the water (current) at a certain number of pounds pressure (volts), as indicated by a pressure gauge (volt-meter) to overcome the friction (resistance) of the pipes (wire) in order that the water (current) may flow at the rate of so many gallons (ampères) per minute, as recorded by the water meter (ammeter). The larger the pipe (wire) the more water (current) can be carried, and the less will be the friction (resistance). Manifestly the pipe

(wire) might be so small that the friction (resistance) would absorb a very large proportion of the power of the pump (dynamo), leaving but little remaining for useful effect. If the pipe (wire) be too large, it will cost too much; if it be too small, the loss will be too great. The pipes (wire) require valves (switches) to regulate and direct the water (current), with fittings (contacts) sufficient to convey the water (current) without leak (drop), and safety relief valves (fusible strips) must be provided to prevent damage from over-pressure (over-voltage).

### 645. Chief Systems of Electrical Transmission.

1. Alternating current—where the current flows in different directions—or the high tension system.

2. The continuous current, or low pressure, or storage system.

3. Pulsating current, continuous in direction, but varying in strength, usually of high tension.

### 646. Board of Trade Division of Systems.

*Low Tension System*, if working below 300 volts with continuous currents, or 150 volts with alternating currents.

*High Tension System*, if working above these limits.

### 647. Comparative Cost of Transmitting Power.

| Method. | 1093 Yards. | | 5465 Yards. | |
|---|---|---|---|---|
| | 10 E.H.P. | 50 E.H.P. | 10 E.H.P. | 50 E.H.P. |
| By cables . . . | 1·77 | 1·35 | 4·69 | 2·65 |
| „ electricity . . | 2·21 | 1·87 | 2·64 | 2·37 |
| „ hydraulics . . | 2·90 | 2·07 | 5·29 | 3·02 |
| „ compressed air . . | 2·98 | 2·29 | 4·66 | 2·99 |

—'*Revue Universelle des Mines.*'

## 648. Electrical Units.

The Volt is the practical unit of electromotive force, or difference of potential or electrical pressure.

The Ohm is the practical unit of resistance, which varies directly as the length and inversely as the area of section of a conductor.

The Ampère, formerly called the Weber, is the practical unit of strength of current, or velocity.

The Coulomb is the practical unit of quantity, and represents the amount of electricity given by one ampère in one second. (The term "coulomb" is becoming obsolete.)

The Farad is the unit of capacity of an electrical receiver; one-millionth of this, or the Microfarad, is taken as the practical unit.

The Watt is the practical unit of work, and is the amount of work required to force one ampère through one ohm during one second.

The Joule is the unit of heating, and represents the heating effect caused by one ampère of current passing through a resistance of one ohm for one second.

The volt may be understood as a measure of pressure, the ampère of quantity, the watt of power; thus a current of 10 ampères at 10 volts = 100 watts.

## 649. Galvanic Batteries

will produce an electric current sufficient for telegraphic or telephonic purposes and electric bells, but not sufficient for lighting. When coupled up in *series*—i.e. copper of first cell to zinc of second, and so on—the electromotive force or "pressure" is increased in proportion to the number of cells. When coupled up *parallel*—i.e. all the coppers to one wire and all the zincs to another—the E.M.F. is the same as from one cell, but the strength of current or "volume" is greater

because the internal resistance is reduced. Coupling up in series gives intensity, and parallel gives quantity.

Common forms are the Leclanché, Grove's, Bunsen's, Daniell's and the Bichromate Batteries.

### 650. Electrical Terms.

An electric current flows in a battery from the *Positive* (or +) *plate* to the *Negative* (or −) *plate*, and outside the battery from the *Positive pole* (connected to the − plate) through *a conductor* to the *Negative pole* (connected to the + plate). If the *Electromotive force*, E.M.F. or *Potential difference* = 1 *Volt*, and the resistance through which the current flows = 1 *Ohm*, the strength of the current = 1 *Ampère*, the quantity of electricity flowing per second = 1 *Coulomb*, and the work per second = 1 *Joule*. If it requires 1 coulomb of electricity to charge a condenser to a potential of 1 volt, the capacity of the condenser = 1 *Farad*. If the mean force of attraction between two opposite charges of electricity = 1 *dyne*, the work done per centimetre displacement = 1 *Erg*. If electricity flows through any measuring instrument, the terminals at which it enters and leaves are *electrodes;* that at which the current enters = *anode*, that at which it leaves = *cathode*. A fluid decomposable by electricity is an *electrolyte*, the products of the decomposition are *ions*.

A volt is about 7 per cent. less than E.M.F. of Standard Daniell cell. An ohm is the resistance of a column of mercury 106·2 cm. long × 1 sq. mm. section, at 0° C. It is about the resistance of a pure copper wire $\frac{1}{20}$ inch diameter and 250 feet long. The legal ohm = ·998 true ohm; B.A. ohm = ·9889 legal ohm = ·987 true ohm. One ampère deposits 1·118 milligrammes of silver per second. The capacity of a knot (6080 feet) of submarine cable is about $\frac{1}{3}$ of a microfarad.

The prefix *meg* multiplies the unit by one million, *micro* divides it by one million, *milli* divides it by one thousand.

*The Board of Trade Commercial Unit* = 1000 Watt-hours = 1·34 H.P. working for an hour. —*C. E. Grove.*

### 651. Measure of Electrical Work.

A = strength of current in ampères.
V = electromotive force in volts.
O = resistance in ohms.
C = quantity of electricity in coulombs.
$t$ = time in seconds.
H.P. = actual horse-power.
W = units of work or watts (1 unit = 10 million ergs absolute C.G.S. measurement).

$$A = \frac{V}{O} = \frac{C}{t}, \qquad C = A\,t.$$

$$\text{H.P.} = \frac{A\,V}{746} = \frac{A^2\,O}{746} = \frac{W}{746}.$$

$$W = A\,V = A^2\,O.$$

1 watt = $\frac{1}{746}$ of a H.P. = 1 volt-ampère = $10^7$ ergs per sec.
1 kilowatt = $10^{10}$ ergs per sec.

### 652. Ohm's Law.

The strength of a current (ampères) varies directly as the electromotive force (volts), and inversely as the resistance (ohms).

### 653. Electrical Equations.

Ampères × volts = Watts.
Joules × time = Watts.
Coulombs per second = Ampères.
Watts ÷ 746 = Effective H.P.
Coulombs ÷ volts = Farads.
·7373 foot-lbs. per second = 1 Joule.
Volts × coulombs = Joules.

## 654. Electric Lighting.

"To make the matter quite clear, let a practical illustration be taken. Let it be supposed that a house has to be lighted by a hundred incandescent lamps, each requiring a current of ·75 of an ampère urged by an electromotive force of 100 volts. The rate at which energy is expended in each lamp, expressed in volt-ampères or watts, of which 746 are equal to a horse-power, will be $\cdot 75 \times 100$, that is 75. The energy expended in the 100 lamps will be at the rate of 7500 watts, which are equal to 10·05 H.P. But this, it must be remembered, is the actual rate at which energy is expended in the lamps. The energy that has to be developed by the engine is greater, for no dynamo-electric machine is perfectly efficient, no dynamo machine gives out as electrical energy the exact equivalent of the mechanical energy expended upon it. Let it be supposed that the machine used in our installation has a 'commercial efficiency' of 80 per cent., that is, that 80 per cent. of the mechanical energy put into the machine reappears in the external or lamp circuit as electrical energy, the balance being wasted in heating the armature coils, and the friction of axles, slipping of belts, and other mechanical sources of loss. Then the rate at which energy is generated by the steam engine must be $10 \cdot 05 \times 1 \cdot 25$, that is 12·55 H.P. This mechanical energy is to be produced by the combustion of coal, and if all the heat liberated in the combustion of coal could be collected and utilised, the supply of coal required to generate energy at the rate of 12·55 H.P. would be very small; but, unfortunately, steam engines even of the best make have but low efficiency, and a horse-power-hour of energy requires in practice somewhere about 4½ lbs. of coal for its production; 12·55 horse-power-hours will therefore require about 56½ lbs. of coal—say, roughly, half a hundredweight, the cost of which is not more than 6*d*. Assuming that the lamps were required to burn for 1800 hours a year—that is,

on an average, nearly 5 hours a day—the annual cost for coal would be 45*l.* The prime cost of a suitable dynamo machine and engine (with boiler) would be, say, 300*l.*, the interest on which at 4 per cent. would be 12*l.*, and the annual depreciation, at 10 per cent., 30*l.*; the cost of attendance would be about 60*l.*; so that the prime cost would be 300*l.*, and the total annual cost 147*l.*, or 1*l.* 9*s.* 5*d.* per lamp."

—*Probert*, 1888.

### 655. Power required for Electric Lighting.

Under good conditions the engine power required equals

| | | | |
|---|---|---|---|
| Arc lights . . | 1 I.H.P. per | 1000 | candle-power. |
| Incandescent lights | 1 „ | 200 | „ |

1 I.H.P. will supply 16 8-candle incandescent lamps.

### 656. Useful Formulæ.

To convert—

| | | |
|---|---|---|
| Mils to millimetres . . | multiply by | ·0253994 |
| Inches „ . | „ | 25·3994 |
| Sq. inches to sq. mm. . | „ | 645·137 |
| Cubic inches to cubic mm. | „ | 16,386·18 |
| Yards to metres . . | „ | ·914383 |
| Miles to kilometres . . | „ | 1·6093 |
| Pounds to kilogrammes . | „ | ·45359 |
| Millimetres to mils . | „ | 39·3708 |
| Millimetres to inches . | „ | ·0373708 |
| Sq. millimetres to sq. ins. | „ | ·00155006 |
| Cubic mm. to cubic inches | „ | ·000061027 |
| Metres to yards . . | „ | 1·09363 |
| Kilometres to miles . . | „ | ·62138 |
| Kilogrammes to lbs. . | „ | 2·204621 |

1 kilometre = 1093·6 yards.
1 mile = 1·6093 kilometres.
1 kilo = 2·2046 lbs.

Pure copper weighs 555 lbs. per cubic foot.

—*Conrady & Co.*

## 657. Electric Wiring.

Table showing legal standard wire gauge, with the equivalent in millimetres. The number of ampères required to fuse it. Safe carrying current in ampères. Number of 100 volt 16-candle-power lamps that it can supply with a drop of 5 per cent. in voltage per 1000 yards. Gauge of tin fuse wire required to protect it.

| S.W.G. | Millimetres. | Safe Current in Ampères. | Ampères that will Fuse it. | Number of 100 Volt Lamps 16 C.P. | S.W.G. of Tin Wire for Safety Fuse. |
|---|---|---|---|---|---|
| 22 | 0·71 | 1 | 45 | 0 | 30 |
| 21 | 0·81 | 2 | 50 | 0 | 27 |
| 20 | 0·91 | 3 | 60 | 1 | 22 |
| 19 | 1·02 | 4 | 75 | 2 | 20 |
| 18 | 1·22 | 5 | 95 | 4 | 20 |
| 17 | 1·42 | 6 | 125 | 5 | 19 |
| 16 | 1·63 | 8 | 170 | 6 | 18 |
| 15 | 1·83 | 10 | 200 | 8 | 17 |
| 14 | 2·03 | 13 | 250 | 9 | 16 |
| 13 | 2·34 | 15 | 300 | 11 | 15 |
| 12 | 2·64 | 20 | 360 | 13 | 14 |
| 11 | 2·95 | 25 | 430 | 16 | 13 |
| 10 | 3·25 | 30 | 500 | 20 | 12 |
| 9 | 3·66 | 35 | 580 | 26 | 11 |
| 8 | 4·06 | 40 | 670 | 33 | 10 |
| 7 | 4·47 | 45 | 790 | 41 | 9 |
| 6 | 4·87 | 50 | 900 | 50 | 8 |
| 5 | 5·38 | 60 | 1100 | 60 | 7 |
| 4 | 5·89 | 70 | 1400 | 75 | 6 |
| 3 | 6·40 | 80 | 1600 | 90 | 5 |
| 2 | 7·01 | 100 | 2900 | 110 | 4 |
| 1 | 7·62 | 120 | 3300 | 140 | 3 |

In running wires, wherever a small wire is branched from a larger one, insert a fuse to protect the smaller wire. Fuses should be on porcelain or slate with screwed covers.

—*Conrady & Co.*

### 658. Light-Testing, or Photometry.

The *standard candle* is a sperm candle, six to the pound, and burning at the rate of 120 grains of spermaceti per hour.

### 659. Coal Gas.

The distribution of the light in numerous jets increases the convenience but decreases the total quantity of light, e.g. :—

| | | | |
|---|---|---|---|
| 5 cub. ft. per hour | burnt in | 1 jet gives a light | = 28 candles |
| ,, | ,, | 2 jets, each $2\frac{1}{2}$ ft., | = 21·16 ,, |
| ,, | ,, | 5 jets, each 1 foot, | = 15 ,, |

### 660. Visibility of Light at a Distance.

| | | | | |
|---|---|---|---|---|
| 1 | candle-power visible at | . . | 1 | nautical mile. |
| 3 | ,, ,, | . . | 2 | ,, |
| 10 | ,, | (with opera glass) | 4 | ,, |
| 19 | ,, | ,, | 5 | ,, |

—*Am. Int. Mar. Cong.*, 1889.

### 661. Mild Steel Cylinders for Storing High Pressure Gases.

Standard pressure for gas = 120 atmospheres.

| | Solid Drawn. | Lap Welded. |
|---|---|---|
| Ultimate tensile strength lbs. per sq. inch sectional area of metal . . . . . | 66,000 | 54,000 |
| Standard sizes: | Thickness. | |
| External diameter, 4 inches . | $\frac{5}{32}$ inch | $\frac{6}{32}$ inch |
| ,, ,, $5\frac{1}{2}$ ,, . | $\frac{7}{32}$ ,, | $\frac{8}{32}$ ,, |
| ,, ,, 7 ,, . | $\frac{9}{32}$ ,, | not made |
| Bursting pressure per sq. inch . | $2\frac{1}{2}$ tons | $2\frac{1}{2}$ tons |
| Limit of elasticity per sq. inch of metal . . . . . | 45,000 lbs. | 35,000 lbs. |
| Actual hydraulic test pressure per sq. inch . . . . | $1\frac{1}{2}$ tons | $1\frac{1}{2}$ tons |

### 662. Cylinders for Compressed Gas.

P = internal bursting pressure tons per sq. inch.
$d$ = internal diameter of cylinder in inches.
$t$ = thickness of sides of cylinder in inches.
$x$ = percentage of extension on the material at the stress $f$ (say 20 per cent. on 10 inches).
$f$ = maximum stress on the material in tons per sq. inch (say 32 tons).

$$P = \frac{2ft}{d\left(1 + \frac{x}{100}\right)}.$$

—*Prof. Goodman.*

# SECTION XIV.

# SUNDRY NOTES AND TABLES.

## 663. Mathematical Concepts.

In arithmetic we deal with *number*, and by inference with *magnitude* or *quantity*. In geometry we add the ideas of *space* and *direction*. In statics we add to the foregoing the idea of *pressure*, and in dynamics we add *force* and *motion*.

## 664. Lineal Measure.

| | |
|---|---|
| 7·92 inches . . . . | = 1 link. |
| 12 inches . . . . . | = 1 foot. |
| 3 feet . . . . . | = 1 yard. |
| 6 feet . . . . . | = 1 fathom. |
| 25 links, or $5\frac{1}{2}$ yards . . . | = 1 rod or pole. |
| 100 links, or 66 feet, or 4 poles . | = 1 chain (Gunter's). |
| 40 poles, or 10 chains . . | = 1 furlong. |
| 320 poles, or 80 chains, or 8 furlongs . . . . | = 1 mile. |
| 6080·27 feet . . . . | = 1 nautical mile. |
| 6080 feet per hour . . . | = 1 Admiralty knot. |

## 665. Square Measure.

| | |
|---|---|
| 144 sq. inches . . . . | = 1 sq. foot. |
| 9 sq. feet . . . . . | = 1 sq. yard. |
| 625 sq. links, or $30\frac{1}{4}$ sq. yards . | = 1 perch. |
| 40 perches, or $2\frac{1}{2}$ sq. chains . | = 1 rood. |
| 100,000 sq. links, 160 perches, 10 sq. chains, or 4 roods . . | = 1 acre. |

| | |
|---|---|
| 43,560 sq. feet, or 4840 sq. yards | = 1 acre. |
| 640 acres . . . . . . | = 1 sq. mile. |

### 666. Cube Measure.

| | |
|---|---|
| 1728 cubic inches . . . . | = 1 cubic foot. |
| 27 cubic feet . . . . . | = 1 cubic yard. |

### 667. Mathematical Signs.

| | |
|---|---|
| $+$ Plus, or add. | $<$ Less than. |
| $-$ Minus, or subtract. | $>$ Greater than. |
| $\times$ Multiply by. | $\propto$ Varies as. |
| $\div$ Divide by. | $\infty$ Infinity. |
| $=$ Is equal to. | $\therefore$ Therefore. |

$\because$ Since.

$\pm$ Plus minus, i.e. either plus or minus, according to circumstances.

$\Sigma$ *Sigma*, the sum, or "summation of the products of."

$\pi$ *Pi*, the ratio of circumference to diameter.

$\theta$ *Theta*, angle of incidence.

$\mu$ *Mu*, coefficient of friction.

$\phi$ *Phi*, angle of repose.

### 668. Arithmetical Terms.

| | | |
|---|---|---|
| Item | Minuend | Multiplicand |
| Item | Subtrahend | Multiplier |
| Sum | Difference | Product |

Divisor) Dividend
Quotient

$$\text{Fraction} = \frac{\text{Numerator}}{\text{Denominator}}.$$

Arithmetical mean of $a$ and $b$ . . $= \dfrac{a+b}{2}.$

Geometrical " . . $= \sqrt{a\,b}.$

Reciprocal of $a$ . . . . $= \dfrac{1}{a}.$

### 669. Nomenclature of Large Numbers.

| | Billions. | Millions. | Thousands. | Units. |
|---|---|---|---|---|
| English | 000,000 | 000,000 | 000 | 000 |

| | Quadrillions. | Trillions. | Billions. | Millions. | Thousands. | Units. |
|---|---|---|---|---|---|---|
| French | 000 | 000 | 000 | 000 | 000 | 000 |

### 670. Duodecimals.

| | | |
|---|---|---|
| | ft. ins. | |
| | ft. ins. | |
| (ft. × ft.) | (ft. × ins.)<br>(ins. × ft.) | (ins. × ins.) |
| sq. ft. | twelfths | sq. ins. |

Commonly called feet, inches and parts.

### 671. Multiplication of Decimals.

Say $12 \cdot 345 \times 6 \cdot 789$.

Ordinary form:

$$\begin{array}{r} 12\cdot345 \\ 6\cdot789 \\ \hline 111105 \\ 98760\phantom{0} \\ 86415\phantom{00} \\ 74070\phantom{000} \\ \hline 83\cdot810205 \\ \hline \end{array}$$

Contracted form:

$$\begin{array}{r} 12\cdot345 \\ 987\cdot6 \\ \hline 74070 \\ 8642 \\ 987 \\ 111 \\ \hline 83\cdot810 \\ \hline \end{array}$$

*Ans.* 83·81.

In 2nd line $7 \times 5 = 35$ $\therefore$ carry 4 to $(7 \times 4)$.
„ 3rd „ $8 \times 4 = 32$ $\therefore$ „ 3 „ $(8 \times 3)$.
„ 4th „ $9 \times 3 = 27$ $\therefore$ „ 3 „ $(9 \times 2)$.

For modern examinations the contracted form of working is alone permissible.

### 672. Prime and Irrational Numbers.

*Prime numbers* are those which have no divisor without remainder, as 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67, &c.

*Irrational numbers*, or *surds*, or *incommensurables* are those for which square roots cannot be expressed, as 2, 3, 5, 6, 7, 8, 10, &c.

### 673. Arithmetical and Geometrical Series.

Arithmetical Series: The *following* number is produced by a constant addition to the *preceding* number, as

$$1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8,$$

or

$$1,\ 3,\ 5,\ 7,\ 9,\ 11,\ 13,\ 15.$$

Geometrical Series: The *following* number is produced from the *preceding* number by a constant multiplier, as

$$1,\ 2,\ 4,\ 8,\ 16,\ 32,\ 64,\ 128,$$

or

$$1,\ 3,\ 9,\ 27,\ 81,\ 243,\ 729,\ 2187.$$

### 674. Types of Vulgar Fractions.

$$\tfrac{3}{16} \times 9 = \frac{3 \times 9}{16}, \qquad \tfrac{3}{4} \times \tfrac{5}{7} = \frac{3 \times 5}{4 \times 7}, \qquad \tfrac{2}{3} \div \tfrac{7}{11} = \frac{2 \times 11}{3 \times 7},$$

$$\tfrac{5}{6} \div 3 = \frac{\frac{5}{6}}{3} = \frac{5}{6 \times 3}, \qquad 3 \div \tfrac{5}{6} = \frac{3}{\frac{5}{6}} = \frac{3 \times 6}{5},$$

$$\frac{\frac{3}{4}}{\frac{5}{8}} = \frac{3 \times 8}{4 \times 5}, \qquad \tfrac{3}{8} \text{ of } 16 = \frac{16 \times 3}{8}, \qquad \frac{4 \times \frac{1}{3}}{7} = \frac{4}{3 \times 7},$$

$$\tfrac{4}{5} \text{ of } \tfrac{5}{7} = \frac{4 \times 5}{5 \times 7}, \qquad \frac{23\frac{4}{5}}{7} = \frac{(5 \times 23) + 4}{7 \times 5} = 3\tfrac{14}{35},$$

$$\tfrac{3}{5} + \tfrac{4}{7} = \left.\begin{matrix} 3 \times 7 = 21 \\ 5 \times 4 = 20 \end{matrix}\right\}41 \atop 5 \times 7 = 35 \;=\; \frac{41}{35}, \qquad \tfrac{3}{5} - \tfrac{4}{7} = \left.\begin{matrix} 3 \times 7 = 21 \\ 5 \times 4 = 20 \end{matrix}\right\}1 \atop 5 \times 7 = 35 \;=\; \frac{1}{35},$$

## 675. Ratio and Proportion.

The ratio of 1 to 2 is $\frac{1}{2}$ or $\cdot 5$; the ratio of $a$ to $b$ is the fraction $\frac{a}{b}$; or in other words, the ratio between two quantities is the proportion the first bears to the second, and is represented by the first divided by the second, thus 1 is the $\frac{1}{2}$ of 2, and $a$ is the $\frac{a}{b}$ of $b$.

## 676. Reduction of Fraction to Lowest Terms.

*Example*:—Reduce $\frac{913}{1079}$ to its lowest terms.

Thus

```
913)1079(1
     913
    ----
     166)913(5
         830
         ---
          83)166(2
             166
             ---
             ...
```

Then, 83 being the least divisor without remainder is the *highest common factor* (H.C.F.), or the *greatest common measure* (G.C.M.), and

$$\frac{913 \div 83}{1079 \div 83} = \frac{11}{13}. \quad \textit{Ans.}\ \text{required.}$$

## 677. Powers and Roots.

$$a \times a = a^2, \quad a^{\frac{1}{2}} = \sqrt{a}, \quad a^{\frac{2}{3}} = (\sqrt[3]{a})^2, \quad a^{3\cdot 5} = a^{\frac{7}{2}} = (\sqrt{a})^7,$$

$$a^{1\cdot 5} = a \times \sqrt{a}, \quad a^{-2} = \frac{1}{a^2}, \quad a^{-\frac{1}{n}} = \frac{1}{a^{\frac{1}{n}}} = \frac{1}{\sqrt[n]{a}},$$

$$a^{\frac{-2}{3}} = \frac{1}{\sqrt[3]{(a^2)}}, \quad a^{\frac{3}{4}} = [\sqrt{(\sqrt{a})}]^3,$$

$$\sqrt{\cdot 75} = \sqrt{75} \div 10, \qquad \sqrt{1\cdot 43} = \sqrt{143} \div 10,$$

$$\sqrt{\cdot 043} = \sqrt{430} \div 100.$$

To square a number ending in $\frac{1}{2}$, multiply the whole number by the next higher and add $\frac{1}{4}$, e.g.

$$17\tfrac{1}{2}^2 = (17 \times 18) + \tfrac{1}{4} = 306\tfrac{1}{4}.$$

### 678. Solving Roots by Factors.

Bear in mind $\sqrt{2} = 1{\cdot}4142$, $\sqrt{3} = 1{\cdot}732$, $\sqrt{5} = 2{\cdot}236$.

*Examples ;*

$$\tfrac{1}{5}(\sqrt{48}) = \tfrac{1}{5}(\sqrt{4 \times 4 \times 3}) = \tfrac{4}{5}(\sqrt{3}) = {\cdot}8 \times 1{\cdot}732 = 1{\cdot}3856.$$
$$\sqrt{{\cdot}75} = \sqrt{{\cdot}5 \times {\cdot}5 \times 3} = {\cdot}5 \times \sqrt{3} = {\cdot}866.$$

### 679. Logarithms.

$a^2 = m$, then 2 is the logarithm of $m$ to the base $a$.
$a^3 = n$ „ 3 „ $n$ „

Tables of logarithms facilitate calculation, addition and subtraction being substituted for multiplication and division, and multiplication and division for involution and evolution.*

### 680. Useful Numbers.

| | |
|---|---|
| $\pi = 3{\cdot}1416$ | $\pi^2 = 9{\cdot}8696$ |
| $\sqrt{\pi} = 1{\cdot}772$ | $\dfrac{1}{\pi} = {\cdot}3183$ |
| $\dfrac{\pi}{6} = {\cdot}5236$ | $\dfrac{\pi}{12} = {\cdot}2618$ |
| $\sqrt{2} = 1{\cdot}414$ | $\sqrt[3]{2} = 1{\cdot}26$ |
| $\sqrt{3} = 1{\cdot}732$ | $\sqrt[3]{3} = 1{\cdot}44$ |
| $\dfrac{1}{\sqrt{2}} = {\cdot}7071$ | $\dfrac{\sqrt{3}}{2} = {\cdot}866$ |

* See the author's 'Practical Trigonometry for Engineers, Architects and Surveyors,' Whittaker & Co. (2*s.* 6*d.* net).

## 681. Epitome of Mensuration.

$a$ = area, $b$ = base, $p$ = perpendicular.
$r$ = radius, $d$ = diameter, $h$ = height.
$n^\circ$ = number of degrees, $c$ = circumference.
$s$ = span or chord. $v$ = versin or rise.

Square $a = \text{side}^2$, side $= \sqrt{a}$.

Rectangle or parallelogram. $a = b\,p$.

Trapezoid (2 sides parallel). $a$ = mean length parallel sides × distance between them.

Triangle, $a = \frac{1}{2}\,b\,p$.

Irregular figure, $a$ = weight of template ÷ weight of sq. inch similar material.

Circle, $a = \pi r^2 = d^2\dfrac{\pi}{4} = \cdot 7854\,d^2 = \cdot 5\,c\,r$.

$c = 2\pi r = d\pi = 3\cdot 1416\,d = 3\cdot 54\sqrt{a}$.

$= \text{approximately } \dfrac{22}{7}\,d$.

Side of equal sq. $= \cdot 8862\,d$.

" inscribed sq. $= \cdot 7071\,d$.

$d = \cdot 3183\,c$.

Segment of circle.

$a$ = sector − triangle.

Length arc $= \cdot 0174533\,n^\circ r = \dfrac{\pi n^\circ r}{180}$.

Approx. ditto $= \frac{1}{3}$ (8 times chord of $\frac{1}{2}$ arc − chord whole arc).

$d = \dfrac{(\frac{1}{2}\text{ chord})^2}{\text{versin}} + \text{versin}$.

Length of arc $= \frac{1}{3}\left(8\sqrt{\dfrac{s^2}{4} + v^2} - s\right)$.

Radius of curve $= \dfrac{s^2}{8\,v} + \dfrac{v}{2}$.

Area of segment

$$= \left\{\left(\frac{s^2}{16\,v} + \frac{v}{4}\right) \times \frac{\left(8\sqrt{\frac{s^2}{4} + v^2}\right) - s}{3}\right\} - \frac{s}{2}\left(\frac{s^2}{8\,v} + \frac{v}{2} - v\right).$$

Do. (Molesworth) $= \frac{4\,v}{3}\sqrt{(0\cdot625\,v)^2 + (\frac{1}{2}\,s)^2}.$

Sector of circle.

$a = \cdot5\,r \times$ length arc.

$a = n^\circ \times$ area circle $\div$ 360.

Ellipse.

$a = \cdot7854\,\mathrm{D}\,d,$ $\qquad c$ approx. $= \sqrt{\frac{\mathrm{D}^2 + d^2}{2}} \times \pi.$

$= \pi\,\mathrm{R}\,r,$ $\qquad = \pi\,\frac{\mathrm{D} + d}{2}.$

Parabola. $a = \frac{2}{3}\,b\,h.$

Cone or pyramid.

Surface $= \frac{\text{circf. base} \times \text{slant length}}{2} +$ base.

Contents = area base $\times \frac{1}{3}$ vert. height.

Sphere.

Surface $= d^2\,\pi.$ $\qquad$ Contents $= \cdot5236\,d^3 = d^3\,\frac{\pi}{6}.$

Frustum of cone.

Contents $= \cdot2618\,h\,(\mathrm{D}^2 + d^2 + \mathrm{D}\,d).$

$= \frac{1}{3}\,h\,(\mathrm{A} + a + \sqrt{\mathrm{A} \times a}).$

Surface $= (\mathrm{C} + c) \times \frac{1}{2}$ slant height + ends.

Segment of sphere.

$r$ = rad. of base, $\qquad$ contents $= \cdot5236\,h\,(3\,r^2 + h^2).$

$r$ = ,, sphere, $\qquad$ ,, $= \frac{1}{3}\,\pi\,h^2\,(3\,r - h).$

Spherical zone, contents $= 1\cdot5708\,h\,(\frac{1}{3}\,h^2 + \mathrm{R}^2 + r^2).$

Prismoidal formula.

Contents $= \frac{\text{end areas} + 4 \text{ times middle area}}{6} \times$ length.

## 682. Colours used in Architectural and Mechanical Drawing.

| Materials. | Elevation. | Section. |
|---|---|---|
| Wrought iron . | Prussian blue, very pale | Prussian blue, dark. |
| Cast iron . . | Payne's grey ,, | Payne's grey ,, |
| Yellow brass . . | Gamboge . . . | Gamboge ,, |
| Gun metal . . | Indian yellow. . . | Indian yellow ,, |
| Steel . . . | Violet carmine, very pale | Violet carmine ,, |
| Lead . . . | Indigo, very pale . . | Indigo ,, |
| Zinc . . . | French blue, very pale . | French blue ,, |
| Leather . . . | Burnt umber ,, . | Burnt umber ,, |
| Chain . . . | Prussian blue, dot and stroke. | |
| Rope . . . | Burnt sienna, dot and stroke. | |
| Copper . . . | Crimson lake and burnt sienna. | Crimson lake and burnt sienna, dark. |
| Fir and deal . . | Burnt sienna, pale . . | Burnt sienna, dark. |
| Oak . . . | Burnt umber ,, . . | Burnt umber ,, |
| Brickwork . . | Roman ochre . . . | Crimson lake ,, |
| Red bricks . . | Light red . . . | Light red ,, |
| York and Bath stone | Sepia, very pale . . | Sepia ,, |
| Granite and Portland stone. | Indigo ,, ,, . . | Indigo ,, |
| Concrete . . | . . . . . . | Payne's grey and sepia. |
| Earth . . . | Ink stippling . . . | Sepia, light and dark. |
| Plaster and cement | Indian ink, pale . . | Indian ink, dark. |
| Slate . . . | Payne's grey . . . | Payne's grey ,, |
| Line of section . | Vermilion, stroke and dot. | |
| Mahogany . . | Light red and burnt sienna. | Light red and burnt sienna, dark. |
| Greenheart . . | Indigo and gamboge . | Indigo and gamboge, dark. |
| Old brickwork . | Indian ink, pale . . | Indian ink, dark. |
| Blue bricks . . | Indigo and indian ink . | Indigo ,, |
| Stone dressings . | French blue, very pale . | French blue ,, |
| Windows inside . | Ditto, washed, pale . | Hooker's green, No. 2, dark. |
| ,, outside . | Payne's grey, washed, dark. | Hooker's green, No. 2, dark. |
| Rain-water pipe . | Prussian blue, outline. | |
| Soil pipe . . | Burnt sienna ,, | |
| Water . . . | Prussian blue, washed . | Prussian blue, lines. |
| Existing timber . | Indian ink, pale . . | Indian ink, etched. |

## 683. Composition of Colours for Drawings.

In the equivalent mixtures named below the first colour is required in the largest proportion.

| Usual Colour. | Equivalent Mixtures. |
|---|---|
| Payne's grey . . . | Indigo, indian ink and crimson lake. |
| Burnt umber . . | Vandyke brown or sepia, and burnt sienna. |
| Roman ochre . . | Yellow ochre, or pale burnt sienna and sepia. |
| Indian red . . . | Light red. |
| Indian yellow . . | Gamboge and pale burnt sienna. |
| Violet carmine . . | Prussian blue and crimson lake. |
| Hooker's green . . | Prussian blue and gamboge. |

## 684. Section Lines in Mechanical Drawing.

The sectional shading to indicate the materials should be as follows:

Cast iron . . thin lines at an angle of 45°.
Wrought iron . alternate thick and thin do.
Brass . . alternate thin and broken lines do.
Steel . . all broken or dotted lines do.
Lead . . thin lines at angle 60° in both directions.
Wood . . rings and rays in imitation of grain.

## 685. Basis of French Measurements.

The mètre professes to be the one-ten-millionth part of the quadrant of the meridian passing through France from Dunquerque to Formentera, but is actually the length, when at the temperature of melting ice, of a platinum rod made by Borda. The exact length is doubtful, viz.:

| | |
|---|---|
| French Academy . . . . . . | 39·3827 inches. |
| Capt. Kater . . . . . . . | 39·37079 „ |
| Mr. Hassler (U.S.). . . . . . | 39·3802 „ |
| Ordnance Department, Great Britain . | 39·37043196 „ |

## 686. French Measures.

1 mètre or 1 m. = 3·281 feet, say 3 feet $3\frac{3}{8}$ inches.

1 decimètre or 1 dm. (very seldom used) = $3\frac{15}{16}$ inches, or nearly 4 inches.

1 centimètre or 1 cm. or 1 c/m. = $\frac{3}{8}$ $\frac{1}{64}$ in., or say $\frac{3}{8}$ in. full.

1 millimètre or 1 mm. or 1 m/m. = $\frac{3}{64}$ in., or about $\frac{1}{20}$ in.

Millimètres par mètre × ·012 = inches to 1 foot.

Weight in lbs. × ·45 = weight in kilos.

Mètres per second × 3·281 = feet per second.

 „ × 196·85 = feet per minute.

Centimètres carrés × ·155 sq. inches.

Kilos. par centimètre carré × 14·22 = lbs. per sq. inch.

Approx. kilos. par c/m. car. × ·9 = tons per sq. foot.

Echelle = scale. Fraction thus $\frac{1}{250}$ gives proportion of drawing to real size.

For useful tables of comparisons see Brook's 'French Measures and English Equivalents' (Spon).

## 687. Equivalents of Metric System.

| | | | |
|---|---|---|---|
| 1 millimetre = | | | ·039 inches. |
| 10 mm. | = 1 centimetre | = | ·3937 „ |
| 10 cm. | = 1 decimetre | = | 3·937 „ |
| 10 dm. | = 1 metre | = | 39·37 „ |

1 inch = 25·4 mm. | 1 kilo = 2·2046 lbs.

## 688. Units in Metric System,

Or centimetre-gramme-second (C.G.S.) system.

Unit length = centimetre = 0·0328 .. feet.

„ mass = gramme = 0·0022046 .. lbs.

„ interval = second.

„ power = 1 gramme raised 1 centimetre in 1 second.

„ velocity = vélo = 1 cm. per second = 0·0328 velos.

„ acceleration = célo = 1 vélo per sec. = 0·0328 celos.

„ force = dyne = 1 gramme × 1 célo.

„ energy = erg = 1 centimetre × 1 dyne.

The weight of a gramme in London is about 981 dynes.

A poundal = 1·3825 .. $\times 10^4$ dynes.

A foot-poundal = 4·214 .. $\times 10^5$ centimetre-dynes (ergs).

A foot-lb. weight = 1·356 .. $\times 10^7$ ergs.

A foot-lb. = 1·3825 .. $\times 10^4$ gramme-centimetres.

An erg (or centimetre-dyne) = 7·37 .. $\times 10^{-8}$ ft.-lb.-wts.

—*Lock's 'Mechanics.'*

| | | | | |
|---|---|---|---|---|
| Foot-lbs. | × | 1·3565 | = | joules. |
| „ | × | ·3262 | = | calories (therms). |
| „ | × | 54404 | = | ergs. |
| „ | × | 13825 | = | g. ergs. |
| „ | × | $g$ | = | foot-poundals. |
| „ | × | ·13825 | = | kilogram-metres. |

Joule's equivalent = 42,000,000 ergs.

If P poundals (or dynes) acting as $w$ lbs. (or grammes) produces acceleration $f$ celos (or spouds)

$$P = wf;$$

but if P is the force of a pound (or gramme) in the old-fashioned gravitation unit employed by engineers, then

$$P = \frac{w}{g} f.$$

689. Units in Foot-second-pound System.

Foot = unit of length.
Second = unit interval of time.
Velo = unit velocity = 1 foot per second.
Celo = unit acceleration = 1 ft. per sec. per second.
Pound or lb. = unit mass.
Poundal = unit force, or force which acting upon 1 lb. produces 1 celo.
1 foot-pound = $g$ foot-poundals.

690. Units employed in Engineering Calculations.

Dimensions in inches.
Loads or forces in lbs.
Stresses in lbs. per sq. inch.
Fluid pressure in lbs. per sq. inch.
Velocities and accelerations in feet per second.
Mechanical work in foot-lbs.

Speeds of rotation in revolutions per minute, or in angular velocity per second.

Statical moments (as bending and twisting moments) in inch-lbs. —*Unwin's 'Machine Design.'*

## 691. Decimal Equivalents to Fractions of an Inch.

| | | | | | |
|---|---|---|---|---|---|
| ·96875 | $= \frac{7}{8} + \frac{3}{32}$ | ·625 | $= \frac{5}{8}$ | ·28125 | $= \frac{1}{4} + \frac{1}{32}$ |
| ·9375 | $\frac{7}{8} + \frac{1}{16}$ | ·59375 | $\frac{1}{2} + \frac{3}{32}$ | ·25 | $\frac{1}{4}$ |
| ·90625 | $\frac{7}{8} + \frac{1}{32}$ | ·5625 | $\frac{1}{2} + \frac{1}{16}$ | ·21875 | $\frac{1}{8} + \frac{3}{32}$ |
| ·875 | $\frac{7}{8}$ | ·53125 | $\frac{1}{2} + \frac{1}{32}$ | ·1875 | $\frac{1}{8} + \frac{1}{16}$ |
| ·84375 | $\frac{3}{4} + \frac{3}{32}$ | ·5 | $\frac{1}{2}$ | ·15625 | $\frac{1}{8} + \frac{1}{32}$ |
| ·8125 | $\frac{3}{4} + \frac{1}{16}$ | ·46875 | $\frac{3}{8} + \frac{3}{32}$ | ·125 | $\frac{1}{8}$ |
| ·78125 | $\frac{3}{4} + \frac{1}{32}$ | ·4375 | $\frac{3}{8} + \frac{1}{16}$ | ·09375 | $\frac{3}{32}$ |
| ·75 | $\frac{3}{4}$ | ·40625 | $\frac{3}{8} + \frac{1}{32}$ | ·0625 | $\frac{1}{16}$ |
| ·71875 | $\frac{5}{8} + \frac{3}{32}$ | ·375 | $\frac{3}{8}$ | ·03125 | $\frac{1}{32}$ |
| ·6875 | $\frac{5}{8} + \frac{1}{16}$ | ·34375 | $\frac{1}{4} + \frac{3}{32}$ | ·015625 | $\frac{1}{64}$ |
| ·65625 | $\frac{5}{8} + \frac{1}{32}$ | ·3125 | $\frac{1}{4} + \frac{1}{16}$ | ·0078125 | $\frac{1}{128}$ |

8ths.

| | | | |
|---|---|---|---|
| $\frac{1}{8}$ = | ·125 | $\frac{5}{8}$ = | ·625 |
| $\frac{1}{4}$ | ·250 | $\frac{3}{4}$ | ·750 |
| $\frac{3}{8}$ | ·375 | $\frac{7}{8}$ | ·875 |
| $\frac{1}{2}$ | ·500 | | |

16ths.

| | | | | | |
|---|---|---|---|---|---|
| $\frac{1}{16}$ = | ·0625 | $\frac{7}{16}$ = | ·4375 | $\frac{13}{16}$ = | ·8125 |
| $\frac{3}{16}$ | ·1875 | $\frac{9}{16}$ | ·5625 | $\frac{15}{16}$ | ·9375 |
| $\frac{5}{16}$ | ·3125 | $\frac{11}{16}$ | ·6875 | | |

32nds.

| | | | | | |
|---|---|---|---|---|---|
| $\frac{1}{32}$ = | ·03125 | $\frac{13}{32}$ = | ·40625 | $\frac{23}{32}$ = | ·71875 |
| $\frac{3}{32}$ | ·09375 | $\frac{15}{32}$ | ·46875 | $\frac{25}{32}$ | ·78125 |
| $\frac{5}{32}$ | ·15625 | $\frac{17}{32}$ | ·53125 | $\frac{27}{32}$ | ·84375 |
| $\frac{7}{32}$ | ·21875 | $\frac{19}{32}$ | ·59375 | $\frac{29}{32}$ | ·90625 |
| $\frac{9}{32}$ | ·28125 | $\frac{21}{32}$ | ·65625 | $\frac{31}{32}$ | ·96875 |
| $\frac{11}{32}$ | ·34375 | | | | |

64ths.

| | | | | | |
|---|---|---|---|---|---|
| $\frac{1}{64}$ = | ·015625 | $\frac{23}{64}$ = | ·359375 | $\frac{45}{64}$ = | ·703125 |
| $\frac{3}{64}$ | ·046875 | $\frac{25}{64}$ | ·390625 | $\frac{47}{64}$ | ·734375 |
| $\frac{5}{64}$ | ·078125 | $\frac{27}{64}$ | ·421875 | $\frac{49}{64}$ | ·765625 |
| $\frac{7}{64}$ | ·109375 | $\frac{29}{64}$ | ·453125 | $\frac{51}{64}$ | ·796875 |
| $\frac{9}{64}$ | ·140625 | $\frac{31}{64}$ | ·484375 | $\frac{53}{64}$ | ·828125 |
| $\frac{11}{64}$ | ·171875 | $\frac{33}{64}$ | ·515625 | $\frac{55}{64}$ | ·859375 |
| $\frac{13}{64}$ | ·203125 | $\frac{35}{64}$ | ·546875 | $\frac{57}{64}$ | ·890625 |
| $\frac{15}{64}$ | ·234375 | $\frac{37}{64}$ | ·578125 | $\frac{59}{64}$ | ·921875 |
| $\frac{17}{64}$ | ·265625 | $\frac{39}{64}$ | ·609375 | $\frac{61}{64}$ | ·953125 |
| $\frac{19}{64}$ | ·296875 | $\frac{41}{64}$ | ·640625 | $\frac{63}{64}$ | ·984375 |
| $\frac{21}{64}$ | ·328125 | $\frac{43}{64}$ | ·671875 | | |

## 692. Whitworth Standard Bolts and Nuts.

Vee threads 55°, $\frac{1}{6}$ depth rounded off top and bottom, depth = ·64 pitch, thickness of nut = diameter of bolt. Weight of head and nut = $1{\cdot}07\,d^3$ for hexagon, or $1{\cdot}35\,d^3$ for square.

| Diam. Bolt. ins. | Threads per inch. | Diam. Bottom Thread. | Area Bottom Thread. | Thickness Head. | Diam. over Flats. | Diam. over Angles. | Diam. of Tapping Hole. |
|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | 12 | ·3932 | ·1215 | ·4375 | ·9191 | 1·0612 | $\frac{7}{16}$ |
| $\frac{5}{8}$ | 11 | ·5085 | ·2030 | ·5468 | 1·1010 | 1·2713 | $\frac{1}{2}+\frac{1}{32}$ |
| $\frac{3}{4}$ | 10 | ·6219 | ·3037 | ·6562 | 1·3012 | 1·5024 | $\frac{5}{8}+\frac{1}{32}$ |
| $\frac{7}{8}$ | 9 | ·7327 | ·4216 | ·7656 | 1·4788 | 1·7075 | $\frac{3}{4}$ |
| 1 | 8 | ·8399 | ·5540 | ·8750 | 1·6701 | 1·9291 | $\frac{7}{8}$ |
| $1\frac{1}{8}$ | 7 | ·9420 | ·6969 | ·9843 | 1·8605 | 2·1483 | $\frac{15}{16}+\frac{1}{64}$ |
| $1\frac{1}{4}$ | 7 | 1·0670 | ·8941 | 1·0937 | 2·0483 | 2·3651 | $1\frac{5}{64}$ |
| $1\frac{1}{2}$ | 6 | 1·2865 | 1·2998 | 1·3125 | 2·4134 | 2·7867 | $1\frac{5}{16}$ |
| $1\frac{3}{4}$ | 5 | 1·4938 | 1·7525 | 1·5312 | 2·7578 | 3·1844 | $1\frac{1}{2}+\frac{1}{32}$ |
| 2 | 4 | 1·7154 | 2·3110 | 1·7500 | 3·1491 | 3·6362 | $1\frac{3}{4}$ |

Bright nuts approx. = $1\frac{1}{2}\,d$ over sides, $1\frac{3}{4}\,d$ over angles. Number of square threads = $\frac{1}{2}$ number V threads. Approximate diameter washer = 2 diameters bolt, or $\frac{1}{4}$ inch more than diameter over angles. (Diameter of bolt in $\frac{1}{8}$ths × 3) + 1 = diameter of tapping hole in $\frac{1}{32}$nds approximately. Approximate diameter bottom of thread $\frac{1}{2}$ inch bolt = ·40, and add ·11 for every $\frac{1}{8}$ inch increase of diameter; or (D in $\frac{1}{8}$ths × ·11) − ·04.

## 693. Whitworth Gas Threads.

*Note.*—Diameter of pipe is measured inside.

| | | | | | |
|---|---|---|---|---|---|
| $\frac{1}{8}$ inch | diameter | = 28 | threads | per inch. |
| $\frac{1}{4}$ to $\frac{3}{8}$ | ,, | ,, | = 19 | ,, | ,, |
| $\frac{1}{2}$ to $\frac{3}{4}$ | ,, | ,, | = 14 | ,, | ,, |
| 1 to 4 | ,, | ,, | = 11 | ,, | ,, |

## 694. British Association (B.A.) Gauge for Apparatus Screws.

This is adopted as the Standard Screw Gauge by the Post Office Telegraphs Department and most large electrical firms.

| Number. | Nominal Dimensions in Thousandths of an inch. | | | Absolute Dimensions in millimetres. | |
|---|---|---|---|---|---|
| | Diameter. | Pitch. | Threads per inch. | Diameter. | Pitch. |
| 25 | 10 | 2·8 | 353 | 0·25 | 0·072 |
| 24 | 11 | 3·1 | 317 | 0·29 | 0·080 |
| 23 | 13 | 3·5 | 285 | 0·33 | 0·089 |
| 22 | 15 | 3·9 | 259 | 0·37 | 0·098 |
| 21 | 17 | 4·3 | 231 | 0·42 | 0·11 |
| 20 | 19 | 4·7 | 212 | 0·48 | 0·12 |
| 19 | 21 | 5·5 | 181 | 0·54 | 0·14 |
| 18 | 24 | 5·9 | 169 | 0·62 | 0·15 |
| 17 | 27 | 6·7 | 149 | 0·70 | 0·17 |
| 16 | 31 | 7·5 | 134 | 0·79 | 0·19 |
| 15 | 35 | 8·3 | 121 | 0·90 | 0·21 |
| 14 | 39 | 9·1 | 110 | 1·0 | 0·23 |
| 13 | 44 | 9·8 | 101 | 1·2 | 0·25 |
| 12 | 51 | 11·0 | 90·7 | 1·3 | 0·28 |
| 11 | 59 | 12·2 | 81·9 | 1·5 | 0·31 |
| 10 | 67 | 13·8 | 72·6 | 1·7 | 0·35 |
| 9 | 75 | 15·4 | 65·1 | 1·9 | 0·39 |
| 8 | 86 | 16·9 | 59·1 | 2·2 | 0·43 |
| 7 | 98 | 18·9 | 52·9 | 2·5 | 0·48 |
| 6 | 110 | 20·9 | 47·9 | 2·8 | 0·53 |
| 5 | 126 | 23·2 | 43·0 | 3·2 | 0·59 |
| 4 | 142 | 26·0 | 38·5 | 3·6 | 0·66 |
| 3 | 161 | 28·7 | 34·8 | 4·1 | 0·73 |
| 2 | 185 | 31·9 | 31·4 | 4·7 | 0·81 |
| 1 | 209 | 35·4 | 28·2 | 5·3 | 0·90 |
| 0 | 236 | 39·4 | 25·4 | 6·0 | 1·00 |

## 695. Birmingham Wire Gauge.

(Till 1st March, 1884.)

| No. | Parts of an inch. | No. | Parts of an inch. | No. | Parts of an inch. |
|---|---|---|---|---|---|
| 5/0 | = 0·500 | 9 | = 0·148 | 22 | = 0·028 |
| 4/0 | 454 | 10 | 135 | 23 | 025 |
| 3/0 | 425 | 11 | 120 | 24 | 0220 |
| 2/0 | 380 | 12 | 109 | 25 | 0200 |
| 0 | 340 | 13 | 095 | 26 | 0180 |
| 1 | 300 | 14 | 083 | 27 | 0160 |
| 2 | 284 | 15 | 072 | 28 | 0140 |
| 3 | 260 | 16 | 065 | 29 | 0130 |
| 4 | 238 | 17 | 058 | 30 | 0120 |
| 5 | 220 | 18 | 050 | 31 | 0100 |
| 6 | 203 | 19 | 041 | 32 | 0090 |
| 7 | 180 | 20 | 035 | 33 | 0080 |
| 8 | 165 | 21 | 032 | | |

This is now obsolete, but is still frequently specified as No. — B.W.G.

## 696. Standard Sheet and Hoop-Iron Gauge (B.G.).

(From March 1st, 1884.)

| No. of Gauge. | Thickness in | | | Approximate Weight per superficial foot of Sheet Iron in pounds. |
|---|---|---|---|---|
| | Ordinary Fractions of an inch. | Decimals of an inch. | Millimetres. | |
| 3° | ½ | ·500 | 12·700 | 20· |
| 2° | .. | ·4452 | 11·288 | 17·808 |
| 1° | .. | ·3064 | 10·068 | 15·856 |
| 1 | .. | ·3532 | 8·971 | 14·128 |
| 2 | .. | ·3147 | 7·993 | 12·588 |
| 3 | .. | ·2804 | 7·122 | 11·216 |
| 4 | ¼ | ·250 | 6·350 | 10· |
| 5 | .. | ·2225 | 5·651 | 8·90 |
| 6 | .. | ·1981 | 5·032 | 7·924 |
| 7 | .. | ·1764 | 4·480 | 7·056 |
| 8 | .. | ·1570 | 3·988 | 6·28 |
| 9 | .. | ·1398 | 3·551 | 5·592 |
| 10 | ⅛ | ·1250 | 3·175 | 5· |
| 11 | .. | ·1113 | 2·827 | 4·452 |
| 12 | .. | ·0991 | 2·517 | 3·964 |
| 13 | .. | ·0882 | 2·240 | 3·528 |
| 14 | .. | ·0785 | 1·994 | 3·14 |
| 15 | .. | ·0699 | 1·775 | 2·796 |
| 16 | $\frac{1}{16}$ | ·0625 | 1·587 | 2·50 |
| 17 | .. | ·0556 | 1·412 | 2·224 |
| 18 | .. | ·0495 | 1·257 | 1·98 |
| 19 | .. | ·0440 | 1·118 | 1·76 |
| 20 | .. | ·0392 | ·996 | 1·568 |
| 21 | .. | ·0349 | ·886 | 1·396 |
| 22 | $\frac{1}{32}$ | ·03125 | ·794 | 1·25 |
| 23 | .. | ·02782 | ·707 | 1·1128 |
| 24 | .. | ·02476 | ·629 | ·9904 |
| 25 | .. | ·02204 | ·560 | ·8816 |
| 26 | .. | ·01961 | ·498 | ·7844 |
| 27 | .. | ·01745 | ·4432 | ·698 |
| 28 | $\frac{1}{64}$ | ·015625 | ·3969 | ·625 |
| 29 | .. | ·0139 | ·3531 | ·556 |
| 30 | .. | ·0123 | ·3124 | ·492 |
| 31 | .. | ·0110 | ·2794 | ·440 |
| 32 | .. | ·0098 | ·2489 | ·392 |
| 33 | .. | ·0087 | ·2210 | ·348 |
| 34 | .. | ·0077 | ·1956 | ·300 |
| 35 | .. | ·0069 | ·1753 | ·276 |
| 36 | .. | ·0061 | ·1549 | ·244 |
| 37 | .. | ·0054 | ·1371 | ·216 |
| 38 | .. | ·0048 | ·1219 | ·192 |
| 39 | .. | ·0043 | ·1092 | ·172 |
| 40 | .. | ·05386 | ·0980 | ·1544 |

## 697. Imperial Standard Wire Gauge.

Table of sizes, weights, lengths and breaking strains of iron wire under the Imperial Standard Wire Gauge issued by the Iron and Steel Wire Manufacturers' Association.

(In force from March 1st, 1884.)

| Size on Wire Gauge. | Diameter. | | Sectional Area in sq. inches. | Weight of | | Length of cwt. | Breaking Strain. | |
|---|---|---|---|---|---|---|---|---|
| | Inch. | Millimetres. | | 100 yards. | Mile. | | Annealed. | Bright. |
| | | | | lb. | lb. | yards | lb. | lb. |
| 7/0 | 0·500 | 12·7 | 0·1963 | 193·4 | 3404 | 58 | 10470 | 15700 |
| 6/0 | 0·464 | 11·8 | 0·1691 | 166·5 | 2930 | 67 | 9017 | 13525 |
| 5/0 | 0·432 | 11 | 0·1466 | 144·4 | 2541 | 78 | 7814 | 11725 |
| 4/0 | 0·400 | 10·2 | 0·1257 | 123·8 | 2179 | 91 | 6702 | 10052 |
| 3/0 | 0·372 | 9·4 | 0·1087 | 107·1 | 1885 | 105 | 5796 | 8694 |
| 2/0 | 0·348 | 8·8 | 0·0951 | 93·7 | 1649 | 120 | 5072 | 7608 |
| 1/0 | 0·324 | 8·2 | 0·0824 | 81·2 | 1429 | 138 | 4397 | 6595 |
| 1 | 0·300 | 7·6 | 0·0707 | 69·6 | 1225 | 161 | 3770 | 5655 |
| 2 | 0·276 | 7 | 0·0598 | 58·9 | 1037 | 190 | 3190 | 4785 |
| 3 | 0·252 | 6·4 | 0·0499 | 49·1 | 864 | 228 | 2660 | 3990 |
| 4 | 0·232 | 5·9 | 0·0423 | 41·6 | 732 | 269 | 2254 | 3381 |
| 5 | 0·212 | 5·4 | 0·0365 | 34·8 | 612 | 322 | 1883 | 2824 |
| 6 | 0·192 | 4·9 | 0·0290 | 28·5 | 502 | 393 | 1544 | 2316 |
| 7 | 0·176 | 4·5 | 0·0243 | 24 | 422 | 467 | 1298 | 1946 |
| 8 | 0·160 | 4·1 | 0·0201 | 19·8 | 348 | 566 | 1072 | 1608 |
| 9 | 0·144 | 3·7 | 0·0163 | 16 | 282 | 700 | 869 | 1303 |
| 10 | 0·128 | 3·3 | 0·0129 | 12·7 | 223 | 882 | 687 | 1030 |
| 11 | 0·116 | 3 | 0·0106 | 10·4 | 183 | 1077 | 564 | 845 |
| 12 | 0·104 | 2·6 | 0·0085 | 8·4 | 148 | 1333 | 454 | 680 |
| 13 | 0·092 | 2·3 | 0·0066 | 6·5 | 114 | 1723 | 355 | 532 |
| 14 | 0·080 | 2 | 0·0050 | 5 | 88 | 2240 | 268 | 402 |
| 15 | 0·072 | 1·8 | 0·0041 | 4 | 70 | 2800 | 218 | 326 |
| 16 | 0·064 | 1·6 | 0·0032 | 3·2 | 56 | 3500 | 172 | 257 |
| 17 | 0·056 | 1·4 | 0·0025 | 2·4 | 42 | 4667 | 131 | 197 |
| 18 | 0·048 | 1·2 | 0·0018 | 1·8 | 32 | 6222 | 97 | 145 |
| 19 | 0·040 | 1 | 0·0013 | 1·2 | 21 | 9333 | 67 | 100 |
| 20 | 0·036 | 0·9 | 0·0010 | 1 | 18 | 11200 | 55 | 82 |

1 mil = $\frac{1}{1000}$ inch.

## 698. Areas of Circles, advancing by Eighths.

| Diam. | Areas. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ·0 | ·1/8 | ·1/4 | ·3/8 | ·1/2 | ·5/8 | ·3/4 | ·7/8 |
| 0 | ·0 | ·0122 | ·0490 | ·1104 | ·1963 | ·3068 | ·4417 | ·6013 |
| 1 | ·7854 | ·9940 | 1·227 | 1·485 | 1·767 | 2·074 | 2·405 | 2·761 |
| 2 | 3·142 | 3·546 | 3·976 | 4·430 | 4·909 | 5·412 | 5·939 | 6·492 |
| 3 | 7·069 | 7·670 | 8·296 | 8·946 | 9·621 | 10·32 | 11·04 | 11·79 |
| 4 | 12·57 | 13·36 | 14·19 | 15·03 | 15·90 | 16·80 | 17·72 | 18·66 |
| 5 | 19·63 | 20·63 | 21·65 | 22·69 | 23·76 | 24·85 | 25·97 | 27·11 |
| 6 | 28·27 | 29·46 | 30·68 | 31·92 | 33·18 | 34·47 | 35·78 | 37·12 |
| 7 | 38·48 | 39·87 | 41·28 | 42·72 | 44·18 | 45·66 | 47·17 | 48·71 |
| 8 | 50·26 | 51·85 | 53·46 | 55·09 | 56·74 | 58·43 | 60·13 | 61·86 |
| 9 | 63·62 | 65·40 | 67·20 | 69·03 | 70·88 | 72·76 | 74·66 | 76·59 |
| 10 | 78·54 | 80·52 | 82·52 | 84·54 | 86·59 | 88·66 | 90·76 | 92·89 |
| 11 | 95·03 | 97·21 | 99·40 | 101·6 | 103·9 | 106·1 | 108·4 | 110·8 |
| 12 | 113·1 | 115·5 | 117·9 | 120·3 | 122·7 | 125·2 | 127·7 | 130·2 |
| 13 | 132·7 | 135·3 | 137·9 | 140·5 | 143·1 | 145·8 | 148·5 | 151·2 |
| 14 | 153·9 | 156·7 | 159·5 | 162·3 | 165·1 | 168·0 | 170·9 | 173·8 |
| 15 | 176·7 | 179·7 | 182·7 | 185·7 | 188·7 | 191·7 | 194·8 | 197·9 |
| 16 | 201·1 | 204·2 | 207·4 | 210·6 | 213·8 | 217·1 | 220·4 | 223·7 |
| 17 | 227·0 | 230·3 | 233·7 | 237·1 | 240·5 | 244·0 | 247·4 | 250·9 |
| 18 | 254·5 | 258·0 | 261·6 | 265·2 | 268·8 | 272·4 | 276·1 | 279·8 |
| 19 | 283·5 | 287·3 | 291·0 | 294·8 | 298·6 | 302·5 | 306·4 | 310·2 |
| 20 | 314·2 | 318·1 | 322·1 | 326·1 | 330·1 | 334·1 | 338·2 | 342·3 |
| 21 | 346·4 | 350·5 | 354·7 | 358·8 | 363·1 | 367·3 | 371·5 | 375·8 |
| 22 | 380·1 | 384·5 | 388·8 | 393·2 | 397·6 | 402·0 | 406·5 | 411·0 |
| 23 | 415·5 | 420·0 | 424·6 | 429·1 | 433·7 | 438·4 | 443·0 | 447·7 |
| 24 | 452·4 | 457·1 | 461·9 | 466·6 | 471·4 | 476·3 | 481·1 | 486·0 |
| 25 | 490·9 | 495·8 | 500·7 | 505·7 | 510·7 | 515·7 | 520·8 | 525·8 |
| 26 | 530·9 | 536·0 | 541·2 | 546·4 | 551·5 | 556·8 | 562·0 | 567·3 |
| 27 | 572·6 | 577·9 | 583·2 | 588·6 | 594·0 | 599·4 | 604·8 | 610·3 |
| 28 | 615·8 | 621·3 | 626·8 | 632·4 | 637·9 | 643·6 | 649·2 | 654·8 |
| 29 | 660·5 | 666·2 | 672·0 | 677·7 | 683·5 | 689·3 | 695·1 | 701·0 |
| 30 | 706·9 | 712·8 | 718·7 | 724·6 | 730·6 | 736·6 | 742·6 | 748·7 |
| 31 | 754·8 | 760·9 | 767·0 | 773·1 | 779·3 | 785·5 | 791·7 | 798·0 |
| 32 | 804·2 | 810·5 | 816·9 | 823·2 | 829·6 | 836·0 | 842·4 | 848·8 |
| 33 | 855·3 | 861·8 | 868·3 | 874·8 | 881·4 | 888·0 | 894·6 | 901·3 |
| 34 | 907·9 | 914·6 | 921·3 | 928·1 | 934·8 | 941·6 | 948·4 | 955·3 |
| 35 | 962·1 | 969·0 | 975·9 | 982·8 | 989·8 | 996·8 | 1003·8 | 1010·8 |
| 36 | 1017·9 | 1025·0 | 1032·1 | 1039·2 | 1046·4 | 1053·5 | 1060·7 | 1068·0 |
| 37 | 1075·2 | 1082·5 | 1089·8 | 1097·1 | 1104·5 | 1111·8 | 1119·2 | 1126·7 |
| 38 | 1134·1 | 1141·6 | 1149·1 | 1156·6 | 1164·2 | 1171·7 | 1179·3 | 1186·9 |
| 39 | 1194·6 | 1202·3 | 1210·0 | 1217·7 | 1225·4 | 1233·2 | 1241·0 | 1248·8 |
| 40 | 1256·6 | 1264·5 | 1272·4 | 1280·3 | 1288·3 | 1296·2 | 1304·2 | 1312·2 |

## 699. Square Roots and Cube Roots.

| No. | Square Roots. | Cube Roots. | No. | Square Roots. | Cube Roots. | No. | Square Roots. | Cube Roots. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1·0000 | 1·0000 | 41 | 6·4031 | 3·4482 | 81 | 9·0000 | 4·3267 |
| 2 | 1·4142 | 1·2599 | 42 | 6·4807 | 3·4760 | 82 | 9·0553 | 4·3444 |
| 3 | 1·7320 | 1·4422 | 43 | 6·5574 | 3·5033 | 83 | 9·1104 | 4·3620 |
| 4 | 2·0000 | 1·5874 | 44 | 6·6332 | 3·5303 | 84 | 9·1651 | 4·3795 |
| 5 | 2·2360 | 1·7099 | 45 | 6·7082 | 3·5568 | 85 | 9·2195 | 4·3968 |
| 6 | 2·4494 | 1·8171 | 46 | 6·7823 | 3·5830 | 86 | 9·2736 | 4·4140 |
| 7 | 2·6457 | 1·9129 | 47 | 6·8556 | 3·6088 | 87 | 9·3273 | 4·4310 |
| 8 | 2·8284 | 2·0000 | 48 | 6·9282 | 3·6342 | 88 | 9·3808 | 4·4479 |
| 9 | 3·0000 | 2·0800 | 49 | 7·0000 | 3·6593 | 89 | 9·4339 | 4·4647 |
| 10 | 3·1622 | 2·1544 | 50 | 7·0710 | 3·6840 | 90 | 9·4868 | 4·4814 |
| 11 | 3·3166 | 2·2239 | 51 | 7·1414 | 3·7084 | 91 | 9·5393 | 4·4979 |
| 12 | 3·4641 | 2·2894 | 52 | 7·2111 | 3·7325 | 92 | 9·5916 | 4·5143 |
| 13 | 3·6055 | 2·3513 | 53 | 7·2801 | 3·7562 | 93 | 9·6436 | 4·5306 |
| 14 | 3·7416 | 2·4101 | 54 | 7·3484 | 3·7797 | 94 | 9·6953 | 4·5468 |
| 15 | 3·8729 | 2·4662 | 55 | 7·4161 | 3·8029 | 95 | 9·7467 | 4·5629 |
| 16 | 4·0000 | 2·5198 | 56 | 7·4833 | 3·8258 | 96 | 9·7979 | 4·5788 |
| 17 | 4·1231 | 2·5712 | 57 | 7·5498 | 3·8485 | 97 | 9·8488 | 4·5947 |
| 18 | 4·2426 | 2·6207 | 58 | 7·6157 | 3·8708 | 98 | 9·8994 | 4·6104 |
| 19 | 4·3588 | 2·6684 | 59 | 7·6811 | 3·8929 | 99 | 9·9498 | 4·6260 |
| 20 | 4·4721 | 2·7144 | 60 | 7·7459 | 3·9148 | 100 | 10·0000 | 4·6415 |
| 21 | 4·5825 | 2·7589 | 61 | 7·8102 | 3·9364 | 101 | 10·0498 | 4·6570 |
| 22 | 4·6904 | 2·8020 | 62 | 7·8740 | 3·9578 | 102 | 10·0995 | 4·6723 |
| 23 | 4·7958 | 2·8438 | 63 | 7·9372 | 3·9790 | 103 | 10·1488 | 4·6875 |
| 24 | 4·8989 | 2·8844 | 64 | 8·0000 | 4·0000 | 104 | 10·1980 | 4·7026 |
| 25 | 5·0000 | 2·9240 | 65 | 8·0622 | 4·0207 | 105 | 10·2469 | 4·7176 |
| 26 | 5·0990 | 2·9624 | 66 | 8·1240 | 4·0412 | 106 | 10·2956 | 4·7326 |
| 27 | 5·1961 | 3·0000 | 67 | 8·1853 | 4·0615 | 107 | 10·3440 | 4·7474 |
| 28 | 5·2915 | 3·0365 | 68 | 8·2462 | 4·0816 | 108 | 10·3923 | 4·7622 |
| 29 | 5·3851 | 3·0723 | 69 | 8·3066 | 4·1015 | 109 | 10·4403 | 4·7768 |
| 30 | 5·4772 | 3·1072 | 70 | 8·3666 | 4·1212 | 110 | 10·4880 | 4·7914 |
| 31 | 5·5677 | 3·1413 | 71 | 8·4261 | 4·1408 | 111 | 10·5356 | 4·8058 |
| 32 | 5·6568 | 3·1748 | 72 | 8·4852 | 4·1601 | 112 | 10·5830 | 4·8202 |
| 33 | 5·7445 | 3·2075 | 73 | 8·5440 | 4·1793 | 113 | 10·6301 | 4·8345 |
| 34 | 5·8309 | 3·2396 | 74 | 8·6023 | 4·1983 | 114 | 10·6770 | 4·8488 |
| 35 | 5·9160 | 3·2710 | 75 | 8·6602 | 4·2171 | 115 | 10·7238 | 4·8629 |
| 36 | 6·0000 | 3·3019 | 76 | 8·7177 | 4·2358 | 116 | 10·7703 | 4·8769 |
| 37 | 6·0827 | 3·3322 | 77 | 8·7749 | 4·2543 | 117 | 10·8166 | 4·8909 |
| 38 | 6·1644 | 3·3619 | 78 | 8·8317 | 4·2726 | 118 | 10·8627 | 4·9048 |
| 39 | 6·2449 | 3·3912 | 79 | 8·8881 | 4·2908 | 119 | 10·9087 | 4·9186 |
| 40 | 6·3245 | 3·4199 | 80 | 8·9442 | 4·3088 | 120 | 10·9544 | 4·9324 |

700. DECIMAL APPROXIMATIONS FOR RAPID CACLULATIONS.

| | | | | |
|---|---|---|---|---|
| Feet . . . | × | ·00019 | = | miles. |
| „ . . . | × | 1·5 | = | links. |
| Yards . . . | × | ·0006 | = | miles. |
| Links . . . | × | ·22 | = | yards. |
| „ . . . | × | ·66 | = | feet. |
| Sq. inches . . | × | ·007 | = | sq. feet. |
| Sq. feet . . | × | ·111 | = | sq. yards. |
| Sq. yards . . | × | ·00021 | = | acres. |
| Acres . . . | × | 4840 | = | sq. yards. |
| Circular inches . | × | ·0055 | = | sq. feet. |
| „ „ . | × | ·7854 | = | sq. inches. |
| Cylindrical inches | × | ·0005 | = | cubic feet. |
| „ „ | × | ·0028 | = | gallons. |
| „ feet . | × | ·0291 | = | cubic yards. |
| „ „ . | × | 4·895 | = | gallons. |
| Cubic inches . | × | ·00058 | = | cubic feet. |
| „ feet . . | × | ·04 | = | cubic yards. |
| „ „ . . | × | 6·232 | = | gallons. |
| „ „ . . | × | ·779 | = | bushels. |
| „ inches . | × | ·00045 | = | „ |
| „ „ . . | × | ·263 | = | lbs. cast iron. |
| „ „ . . | × | ·282 | = | lbs. wrought iron. |
| „ „ . . | × | ·283 | = | lbs. steel. |
| Bushels . . | × | 1·284 | = | cubic feet. |
| Gallons . . | × | ·1605 | = | „ „ |

# APPENDICES

# APPENDIX I.

*Session* 1896-97.

## Syllabus of City and Guilds of London Technical Institute in

(11) Gas Manufacture.
(12) Iron and Steel Manufacture.
(38) Telegraphy and Telephony.
(39) Electric Lighting and Power Transmission.
(41) Metal Plate Work.
(46) Mechanical Engineering.
(68) Manual Training—Metal Work.

## 11.—GAS MANUFACTURE.

**I. Syllabus.**—The Examination will include questions founded on such subjects as the following:—

### Ordinary Grade.

1. The construction of a retort or oven best adapted for the destructive distillation of coal.

2. The setting of retorts, and construction of retort furnaces.

3. The effects of temperature in modifying the quantity and quality of the gas produced.

4. The description and arrangement of apparatus employed for the conveyance of the gas immediately upon its leaving the retorts.

5. The description of apparatus best adapted for cooling the gas.

6. The most suitable condition of the gas for effective purification.

7. A description of the various instruments used in gas-works for ascertaining and recording pressure and exhaust.

8. The laying of mains and service pipes.

9. The construction of gas meters.

10. The fixing of meters and the fitting up of premises for the supply of gas.

11. A description of the various kinds of gas burners in general use.

12. The use of an exhauster.

13. The methods employed for controlling pressure at the works, so as to secure an adequate supply of gas at the various points of consumption, with a due regard for economical effect.

14. The simplest methods of ascertaining the purity and illuminating power of gas.

15. A description of the materials and methods employed for the purification of gas.

16. Influence of temperature and atmospheric pressure upon the volume of gas.

17. A description of the various tests employed for determining the values of ammoniacal liquor and spent oxide.

### Honours Grade.

In the Honours Examination more difficult questions will be set in the above subjects, and in addition a knowledge will be required of:—

1. The characteristic properties of the various kinds of coal, and their value for gas-making purposes.
2. The effects of temperature upon the production of residuals.
3. The chemical composition of coal gas.
4. The chemistry of purification.
5. Gas analysis.
6. The development of illuminating power.
7. The practice of photometry.
8. Labour saving appliances in the retort house, and the working of retorts.
9. The construction of gasholders, purifiers and other gas apparatus.
10. The working up of ammoniacal liquor.
11. The principles of combustion, and their application to the working of retort furnaces.
12. Carburetted water gas.
13. The enrichment of coal gas by means of oil, &c.

**II. Full Technological Certificate.**—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see Rules 40–1) will also be required to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least in *two* of the following Science subjects:—

II. Machine Construction and Drawing.
VII. Applied Mechanics.
VIII. Light and Heat.
X. Inorganic Chemistry.
XI. Organic Chemistry.
XII. Geology.
XIX. Metallurgy.
XXII. Steam.

**III. Works of Reference.**—Treatise on the Science and Practice of the Manufacture and Distribution of Coal Gas (King, 11 Bolt Court, E.C.); Newbigging's Handbook for Gas Engineers and Managers (King); Richards on Gas Works (Spon); Dibdin's Practical Photometry (King); Thorpe's Quantitative Analysis (Longmans); Thorpe's Dictionary of Applied Chemistry, article on Gas (Longmans); Cripps' The Guide Framing of Gasholders (King); (The Chemistry of Gas Manufacture, by W. J. A. Butterfield (Griffin); The Journal of Gaslighting, with special reference to Lecture on Gas Manufacture by C. Hunt, vol. 51, and

the articles on Coal Gas, its Manufacture, Distribution and Consumption, vols. 59, 60, 61 and 62; Gas Engineers' Laboratory Handbook by G. Hornby; Gas Manufacture, by J. Hornby (Bell and Sons). Transactions of the Incorporated Gas Institute; Transactions of the Incorporated Institution of Gas Engineers. Articles on Coal Gas, by L. T. Wright, in Thorpe's Dictionary of Applied Chemistry (Longmans).

## 12.—IRON AND STEEL MANUFACTURE.

**I. Syllabus.**—The Ordinary Grade is limited to the portions of the Syllabus enclosed within brackets thus [ ]. The Honours Grade includes the whole Syllabus. The Examination will include questions founded on such subjects as the following :—

1. [Composition and general characters of the chief iron ores. Preparation of raw ores for smelting; changes in composition thereby produced.] Mechanical preparation of iron ores. Magnetic concentration.

2. [Construction and mode of working of blast furnaces, and subsidiary appliances.]

3. [Nature of fluxes requisite under various conditions. Composition of slags. Utilisation of blast furnace cinder, and of forge and mill cinder in the blast-furnace.]

4. Hot and cold blast; effects of these and of variations in amount of fuel and flux, and in their nature, on the production and character of the iron made.

5. [Characters of pig iron from various kinds of ore; effects of foreign elements on these characters.] Characters and methods of preparation of spiegeleisen, ferro-manganese, ferro-chrome, and other alloys of iron.

6. [General chemical and physical distinctions between pig iron, wrought iron and steel.] Modern classification of iron and steel. Physical properties of iron and steel.

7. Methods of casting iron and steel. Foundry appliances and operations. Furnaces, crucibles and moulds, &c., requisite for large steel castings. Malleable iron castings; chilled castings.

8. [Conversion of pig iron into malleable iron in open hearths; refining, puddling and boiling; fettling, and its uses; hand and machine puddling. Machinery and appliances requisite, such as helves, hammers, squeezers, rolls, &c.] and hydraulic forging machinery, steam hammers, rolling mills, and their respective advantages and disadvantages. Manufacture of bars, plates, rods, rails, tyres, hoops, wire, cold rolled shafting, &c.

9. [Conversion of malleable iron into steel. Blister, shear and cast steel. The effects of the presence of carbon, silicon, phosphorus, sulphur and manganese.]

10. [Conversion of pig iron into steel. Puddled steel. Acid and basic-Bessemer processes. Acid and basic open hearth processes] and other analogous special processes.

11. [Production of malleable iron or steel direct from the ore. Small blast furnaces. Catalan forge, Wootz, Chenot, Siemens], Husgafvel and other analogous processes.

12. Machinery and appliances requisite for manufacture of cast steel, Bessemer steel, and other kinds of steel largely used, including steel compressing machinery.

13. The variations occurring in the qualities of different kinds of steel, the causes of these variations, and the methods by which the various sources of imperfection may be best avoided or overcome.

14. [The nature of the physical] and chemical [tests of the qualities of iron and steel, and the effects on these qualities of foreign elements. Comparative strength of iron and steel.]

15. [Hardening and tempering of steel, including the use of oil, water and cold surfaces; precautions to be used in reheating large masses of steel, to avoid fracture.] General principles involved.

16. [Case-hardening.]

17. [Welding of iron and steel. Conditions requisite to produce good welds.]

18. [General nature of the leading chemical and physical changes occurring during the smelting of pig iron, its conversion into malleable iron, and the production of steel of various kinds.]

19. Machinery for cutting, shaping and working wrought iron.

20. Preparation of tin and tern plates, and of galvanised iron sheets, plain and corrugated.

21. Methods of analyses relating to iron and iron ores.

**II. Full Technological Certificate.**—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see Rules 40–1) will also be required to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least in *two* of the following Science subjects:—

| | |
|---|---|
| II. Machine Construction and Drawing. | VII. Applied Mechanics. |
| VI. Theoretical Mechanics. | X. Inorganic Chemistry. |
| | XIX. Metallurgy. |

**III. Works of Reference.**—In addition to the smaller text-books on the metallurgy of iron and steel, students may consult Percy's Iron and Steel; Sir L. Bell's Principles of the Manufacture of Iron and Steel; Turner's Metallurgy of Iron; and Howe's Steel; also the article Iron in the Encyclopædia Britannica, and should especially refer to the Journal of the Iron and Steel Institute for accounts of new processes and inventions, and experimental researches and trials, &c., published since the formation of the Institute, whereby much valuable practical information may be obtained. Much valuable information may also be gained from the Transactions of the Institute of Civil Engineers and the American Institute of Mining Engineers. Students who read German will find the works of Dr. Wedding and Professor Ledebur of great assistance.

## 38.—TELEGRAPHY AND TELEPHONY.

**I. Syllabus.**—The Examination will include questions founded on such subjects as the following:—

### Ordinary Grade.

1. The fundamental principles of electricity in their application to the Electrical Engineering industries.

2. Units of Measurement. Standards of resistance, their practical construction and adjustment; electromotive force and capacity; effects of temperature variation.

3. Galvanometers—principles and manufacture of—(*a*) absolute, (*b*) sensitive, (*c*) dead beat, (*d*) astatic, (*e*) differential. Shunts, ordinary and constant resistance.

4. Resistance coils—construction of; gauge and kind of wire for; methods of winding and insulating.

5. Condensers—construction and testing of.

6. Instruments necessary for the equipment of an electrical testing room—(*a*) for land telegraph lines, (*b*) for cables; methods of using the apparatus in the simpler forms of testing; apparatus required by linemen.

7. Electrical testing as applied to the inspection of apparatus and to the detection and removal of faults.

8. Essential qualities of iron and steel for temporary and permanent magnets respectively; methods of making permanent magnets; treatment of iron for electro-magnets; simple calculations as to the effective power of a permanent magnet or an electro-magnet.

9. The construction of telegraph and telephone lines, overhead and underground.

10. The construction of submarine cables and the simpler of the phenomena connected therewith.

11. The simpler systems of telegraphy worked by hand, including the double current duplex.

12. Batteries used in telegraphy and telephony; principles, action and construction; methods of grouping; universal battery working; application of secondary batteries to universal working.

13. The principles involved in the electrical transmission of sound and speech; the various systems of telephony and the instruments employed therein, including receivers, transmitters, call bells, and exchange switchboards.

14. Faults in land and submarine lines; their nature, and the general principles of localisation.

15. Nature and methods of preventing disturbances and damage by earth currents and lightning.

16. Testing of materials employed in the construction of lines and apparatus.

### Honours Grade.

*Candidates for Honours must have previously passed in the Ordinary Grade.*

In the Honours Examination, which may be either in—I. Telegraphy, or, II. Telephony, more difficult questions will be set in the subjects of the Ordinary Grade, and in addition a knowledge will be required of:—

### SECTION I.—TELEGRAPHY.

1. The systems of high speed, quadruplex, multiplex and type-printing telegraphs actually in use in Great Britain.
2. The manufacture, laying, testing, working and repairing of submarine cables.
3. Practical methods for the supply of current, other than by primary batteries.
4. The commercial adaptability of the various systems of telegraphy.
5. The Wheatstone bridge, tangent galvanometers and reflecting galvanometer, in theory and practice.
6. Repeaters—principles and construction of; employment and adjustment of, for single and double current, simplex and duplex circuits.
7. Causes limiting the speed of automatic telegraph working, and methods of reducing and increasing them.
8. Making of working drawings for simple telegraph apparatus.
9. Daily and other periodic tests in theory and practice.

### SECTION II.—TELEPHONY.

1. Transmitters and Receivers—various forms, construction and special features of; adjustment of materials for.
2. Induction coils—object of. Translation from single wire to double wire systems by means of.
3. Methods of working telephones and telegraph instruments simultaneously on the same wire; theory of.
4. Conditions which limit the distance to which telephonic transmission is possible; use of iron and copper wires.
5. Metallic loop system of working—advantages of; inductive disturbances and methods of overcoming them; theory of methods.
6. Call bells—magnets and battery bells; magneto calls; construction of.
7. Individual calls for several stations on one circuit—theory and practical arrangement of.
8. Exchange switchboard systems for single and for double wires. Multiple switches.
9. Switches, intermediate, &c.
10. Automatic call boxes.
11. Hughes' Induction Balance.

**II. Full Technological Certificate.**—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see Rule 38) will also be required to have passed the Science and Art Department's Examination, in the Elementary Stage at

least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

| | |
|---|---|
| V. Mathematics. | VIII. Sound, Light and Heat. |
| VI. Theoretical Mechanics. | IX. Magnetism and Electricity. |
| VII. Applied Mechanics. | X. Inorganic Chemistry. |

**III. Works of Reference.**—Culley's Handbook of Telegraphy (Longmans); S. P. Thompson's Electricity and Magnetism (Macmillan); Fleeming Jenkin's Electricity (Longmans); Ayrton's Practical Electricity (Cassell); Stewart and Gee's Practical Physics (Macmillan); Bottone's Electrical Instrument Making (Whittaker); Maycock's First Book of Electricity and Magnetism (Whittaker); Noad's Student's Textbook of Electricity (Crosby Lockwood); Preece and Sivewright's Telegraphy (Longmans); Preece and Stubbs' The Telephone (Whittaker); Slingo and Brooker's Electrical Engineering (Longmans); Kempe's Handbook of Electrical Testing (Spon); Munro and Jamieson's Electrical Rules and Tables (Griffin); Poole's Practical Telephone Handbook (Whittaker); Bell's Telegraphist's Guide (Office of Electricity).

## 39.—ELECTRIC LIGHTING AND POWER TRANSMISSION.

With the view of encouraging Artisans to take a complete course of instruction in this subject, an Elementary Examination will be held preliminary to that in the Ordinary Grade. No certificates will be given to candidates on the results of the Preliminary Examination only, but their successes will be notified to the centre at which they were examined.

Candidates may take the Ordinary Grade without having passed the Preliminary, or both Examinations may be taken in the same year. Those who pass the Preliminary Examination as well as the Examination in the Ordinary Grade (whether in the same or in a previous year) will not be required to produce a Science and Art Department's Certificate in the subject of Electricity and Magnetism before they are eligible for the full Technological Certificate, and only one Science Certificate will be required. In the Preliminary Examination no questions will be set involving calculations beyond the ordinary rules of arithmetic as applied to such matters as Ohm's Law: nor will any questions be asked concerning the chemical applications of electric currents.

Wiremen who are candidates for the Certificate in the Wiremen's Examination will, after passing the Preliminary Examination, be eligible to proceed to the Practical Examination for Wiremen to be held later in the summer.

The Preliminary Examination will be held on Monday, May 3rd, from 7 to 10.

In the Ordinary Grade questions will be set that presuppose an acquaintance with elementary algebra including quadratic equations, and a knowledge of the simple trigonometrical quantities, sine, cosine, &c. The candidate must be able to plot values in the form of curves. He is strongly recommended to learn the use of the slide-rule, and should bring

one to the Examination, or he may use in calculation a table of four-figure logarithms. Greater accuracy in working out examples than can be obtained by the use of the slide-rule is not required. In marking the answers the Examiners will take note not only of the correctness of the results, but also of the methods used. Simple common-sense methods in which the general accuracy of the work can be tested step by step are to be preferred to the use of long and complicated formulæ. Candidates are expected to be able to make simple *hand-sketches showing sizes of parts.*

The Examination in the Ordinary Grade will be held on Tuesday, May 4th, from 7 to 10.

In the *Honours Grade* there are three sections corresponding to the three main branches of the electrical engineering industry. The candidate must elect for himself in which of the three sections he desires to be examined. The examination will be confined *solely* to the single section he selects, and any questions may be asked on the subjects contained in this section, such as can be answered by a practical electrical engineer who has devoted himself specially to these subjects. In the Honours Grade the candidate may, during the examination, use an Electrical Engineering Pocket Book; but if he avail himself of this, he must state the title of the book on his answer paper, and in his answers give references to the pages of the book he has consulted.

The Examination in the Honours Grade will be held on Tuesday, May 4th, from 7 to 10.

**I. Syllabus.**—The Preliminary Examination will include questions founded on the following subjects:—

1. General notions about electro-motive force, current, resistance and the principles of electric circuits, simple and branching. The voltage required to produce any required current in a wire of given resistance. Simple descriptive knowledge of battery cells and of accumulators.

2. The construction and action of electric bells; the arrangements of battery cells and of circuits for bells. Use of relays.

3. General descriptive knowledge of magnets and electro-magnets. Best methods of winding electro magnet coils for various services.

4. Simple principles and use of electric measuring instruments, ampère-meters, volt-meters, delicate mirror galvanometers, resistance coils.

5. The induction of currents by motion of magnets. Notions about magnetic lines of force. Magneto-generators for electric bells. Simple descriptive knowledge of the common sorts of dynamos and alternators.

6. The induction of currents by action of currents in neighbouring circuits. The effect of iron cores. Simple descriptive knowledge of induction coils and of transformers for alternate currents.

7. Simple principles of electric motors and of electro-magnetic mechanism. The magnetic drag on wires carrying currents.

8. Elementary descriptive knowledge about Glow lamps and Arc lamps, and their arrangement in parallel and in series. The necessary parts of Arc lamps, and their action.

9. The relations between mass, weight and force. Distinction between work and power. Relations between heat and work. Relation between the watt, the kilowatt, and the horse-power. Watt-meters.

10. Systems of wiring houses. Methods of jointing. General know-

ledge about conducting and insulating materials and their mechanical and electrical properties. Wiring rules. Meaning and calculation of drop.

Practical Examination for Wiremen.—The Practical Examination for Wiremen will be held at different centres, where the necessary arrangements can be made, and as soon as possible after the Preliminary Written Examination, at a date to be subsequently fixed. Notice of what the Candidates are required to bring with them to the Examination will be given at the time of the Written Examination. The extra fee for this Examination is One Shilling.

## Ordinary Grade.

*In addition to the subjects for the Preliminary Examination, Candidates for the Ordinary Grade Certificate are expected to be acquainted with the following matters, except the parts contained in brackets* [ ].

1. Comparison between the British units of mechanical measurement, and the international units based on the centimetre and the gramme.
2. The laws of Ohm and of Faraday respecting steady currents. Laws of Helmholtz and of Maxwell respecting sudden and periodic currents. Simple properties of alternate currents.
3. Electric measuring instruments for the workshop. Wheatstone's bridge. Standards of resistance, electro-motive force and capacity.
4. Practical ampère-meters, volt-meters and watt-meters. Electro-dynamometers, current balances, electrostatic volt-meters, hot wire instruments.
5. Magnetic properties of materials, magnetising force, induction and permeability. Hysteresis. [Methods to determine these quantities.]
6. The selenoid and its properties. The electromagnet [and its adaptations to electro-mechanical devices.]
7. Mechanical strength and electric properties of materials. Conductivity of metals and alloys, and its change with temperature. Mechanical qualities and resistance of insulating materials, and the influence of temperature. [Testing of insulation resistance. Ohm-meters.]
8. Condensers. Work stored in a condenser. [Dielectric strength of insulating materials and its relation to mechanical strength, incombustibility and specific inductive capacity.]
9. Fundamental points of magneto-electric induction. Self and mutual induction. [Induction balances. Standards of self-induction.]
10. Outline of the theory of continuous-current dynamos and motors. Characteristic curves. Simple cases of transmission of power.
11. The magnetic circuit as applied to dynamo machines. Types of field magnets and armatures, considered magnetically.
12. The winding of field magnets and armatures.
13. The mechanical features of dynamos and motors as regards strength of parts, heating, durability, ease of repair, construction of brushes, commutators, terminals, &c.

14. Motor generators, fundamental rules as to winding, speed and output.

15. The electrical and mechanical efficiency of dynamos and motors. [Methods of determining efficiency.]

16. The construction and elementary theory of alternators and transformers. [Alternate-current motors.]

[17. The efficiency of alternate-current apparatus.]

[18. The transmission of power by alternate and polyphase currents.]

19. Practical method of arranging lamps and circuits.

20. Glow lamps and arc lamps, watts per candle. [Photometry, illumination of rooms and open spaces.]

21. Secondary batteries, construction, and maintenance.

[22. Supply meters. Meter testing.]

23. Distribution of electrical energy from central stations, direct and transformer systems, continuous and alternating currents, two wire and multiple-wire mains.

[24. Central Stations. Load Diagrams. Conduits.]

## Honours Grade.

*Candidates for Honours must have previously passed in the Ordinary Grade.*

Candidates will be examined in one of the following Sections:—

Section. I.—Electrical Instruments and Regulating Appliances; their construction, use, &c.; or,

Section II.—Dynamos, Motors, Accumulators and Transformers; their construction, use, &c.; or,

Section III.—Light and Power Distribution, Mains and Central Stations.

The candidate for the Honours Grade Examination must elect in which of the three sections he desires to be examined. The examination will be confined *solely* to the single section he selects, and any questions may be asked on the subjects contained in this section, such as can be answered by a practical Electrical Engineer who has devoted himself specially to these subjects.

### SECTION I.—ELECTRICAL INSTRUMENTS, &c.

More difficult questions will be set in subjects 1 to 10 inclusive, including the subjects contained in brackets, and in addition, a knowledge will be required of:—

Galvanometers, sensitive, aperiodic, differential, ballistic. Use of shunts. Calibration of instruments. Measurement of very large and very small resistances. Instruments for alternate currents. Switchboards; safety devices; automatic regulators. Portable instruments for electric and magnetic measurements. Photometry. Supply meters; meter testing.

### SECTION II.—DYNAMOS, &c.

More difficult questions will be set in subjects 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, including those in brackets, and in addition a knowledge will be required of:—

The designing of dynamos for arc and incandescent lighting, of alternators and transformers; armature winding; armature reaction; heating and sparking of machines; parallel working of alternators; the construction of motors for special purposes, and gearing of same. Polyphase machines.

SECTION III.—ELECTRIC LIGHT AND POWER.

More difficult questions will be set in subjects 4, 9, 12, 13, 14, 17, 18, 19, 20, 21, including those in brackets, and in addition a knowledge will be required of:—

Electric transmission and distribution of power by continuous and alternating currents, electric railways and tramways, private electric light installations, the electrical equipment of central stations, including arrangement of dynamos, batteries, switchboard and regulating appliances; overhead and underground mains; safety devices, testing devices, fire office rules; sizes of the feeders and mains in the two and three wire systems; use of substations.

**II. Full Technological Certificate.**—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see *above* and Rules 40–1) will also be required to have passed the Science and Art Department's Examination, in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

II. Machine Construction and Drawing.
V. Mathematics.
VI. Theoretical Mechanics.
VII. Applied Mechanics.
VIII. Sound, Light and Heat.
IX. Magnetism and Electricity.

**III. Works of Reference.**—Absolute Measurements in Electricity and Magnetism, by A. Gray (Macmillan); Practical Electricity, Ayrton (Cassell); Dynamo-Electric Machinery, by S. P. Thompson (Spon); Alternate Current Transformers, by R. W. Weekes (Biggs); Electric Lamps, by J. A. Fleming (Biggs); The Incandescent Lamp, by G. S. Ram (Electrician Office); Theory of Alternating Currents, by Bedell and Crehore; Magnetic Induction, by J. A. Ewing (Electrician Office); Electric Transmission of Energy, by Kapp (Whittaker); Electrical Engineering, by Slingo and Brooker (Longman); The Dynamo, by Hawkins and Wallis (Whittaker); Dynamo Machinery, by J. Hopkinson (Whittaker): Electric Light and Power, by A. F. Guy (Biggs); Photometry, by A. Palaz; Transformers, by G. Kapp (Whittaker, 1895); The Alternate Current Transformer, by J. A. Fleming (Electrician Office); The Electromagnet, by S. P. Thompson (Spon); Electric Light Cables and the Distribution of Electricity, by S. A. Russell (Whittaker); The Electric Railway, by Crosby and Bell (Whittaker); Electric Traction, by A. Reckenzaun (Biggs); Polyphase Currents, by S. P. Thompson (Spon). The current electrical periodicals. The Journal of the Institution of Electrical Engineers.

## 41.—METAL PLATE WORK.

**1. Syllabus.**—The Examination will include questions founded on such subjects as the following :—

### Ordinary Grade.

1. Calculations for dimensions of vessels to hold given quantities ; sizes of main and branch pipes for stoves and ventilating purposes. Weights, sizes and gauges of sheets, wire, rivets, &c.

2. The setting-out of patterns for elbows formed by circular, oval and oblong pipes meeting at any angle ; T-elbows, tapering Y-pieces, bends, &c. Patterns for round, oval, oblong and other simple forms of equal tapering bodies used by boilermakers, coppersmiths, iron, zinc and tin-plate workers.

3. Shape of notches, and allowances for lap, wire, &c., for seams of various kinds. Methods of joining sheet-metal by—(*a*) soldering, (*b*) riveting, and (*c*) grooving.

4. Solders and soldering. Composition and uses of hard and soft solders. Theory and practice of soldering, brazing, autogenous soldering, fluxes, useful alloys, &c.

5. Annealing, stretching, raising, planishing and general principles of working up sheet copper, brass, zinc, iron (plain and coated).

6. The various hand and machine tools used in metal plate work. Comparison of hand and machine tools for special work.

It is important that candidates should acquire facility in the production of clear and neat working drawings, and give answers which show their practical connection with some branch of metal plate work.

### Honours Grade.

*Candidates for Honours must have passed in a previous year in the Ordinary Grade.*

**1.** Written Examination.—In the written Examination more difficult questions will be set in some of the above subjects, and in addition candidates will be required to show a knowledge of:—

(1) The physical and chemical properties of iron, lead, antimony, aluminium, bismuth, mercury, tin, zinc, copper, nickel and silver.

(2) Alloys. The composition and properties of brasses, bronzes, tin-plate, galvanised iron, &c. Tinning processes.

(3) Fuel: composition and physical character of various kinds, and the modes of applying them in metal plate work.

(4) Patterns and working drawings to scale of a more advanced character will be required.

**2.** Practical Work.—Each candidate will also be required to execute in suitable material, in the year preceding the Examination, an original piece of work, and to forward the same to London (carriage paid) a week prior to the date of the Written Examination. The specimen of work must be accompanied by a working drawing, with particulars of the quantity and nature of the materials used, and must be of such dimensions

that it can fit into a box not larger than two cubic feet. A certificate signed by the candidate's employer, or by the class teacher and a member of the School Committee, stating that the work has been executed by the candidate himself, without assistance, *must be forwarded with the specimen.* The work should be such as will show the candidate's skill in the more important branches of metal work in which he is engaged.

**II.** Full Technological Certificate.—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see Rules 40–1) will also be required to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade in the Advanced Stage at least, in *two* of the following Science subjects:—

I. Practical, Plane and Solid Geometry.
II. Machine Construction and Drawing.
VI. Theoretical Mechanics.
VII. Applied Mechanics.
X. Inorganic Chemistry.
XIX. Metallurgy.

Certificates showing that the candidate has passed the Elementary Examination of the Science and Art Department in Geometrical Drawing, as well as in Freehand or Model Drawing, will be accepted in lieu of one of the above Science subjects for the full Technological Certificate in either grade of the Examination.

**III.** Works of Reference:—Byrne, Practical Metal-Worker's Assistant (Philadelphia); Miller's Chemistry, vol. ii.; Bloxam and Huntington, Metals (Longman, Green & Co.); Davidson, Drawing for Metal Plate Workers (Cassell & Co.); Metal Plate Work, C. T. Millis (Spon).

## 46.—MECHANICAL ENGINEERING.

### Ordinary Grade.

The Examination in the Ordinary Grade will consist of two parts, which will be held in the same year. To obtain a Certificate or Prize, the candidate must pass in both parts of the Examination in the same year. The fee for the entire examination is Two Shillings.

#### PART I.

The Examination in Part I. will be held on Monday, May 3rd, 1897, from 7 till 10.

Candidates will be examined in *two* only of the following three divisions:—

(*A*) The modification of velocity and effort by mechanism. Kinematic chain and elementary machine. Transmission of motion by linkwork, belts, toothed gearing and hydraulic connection. Mechanisms derived from the simplest kinematic chains. Velocity and effort curves. Relation of velocity and acceleration curves.

(*B*) Elementary relations of stress and strain. The strength of materials to resist tension, compression, shearing, torsion and bending. Application of the rules of the strength of materials to the design of the simpler machine elements. Considerations which determine factors of safety.

(*C*) The theory of the action of the steam engine and boilers so far as it can be dealt with without thermodynamics. Indicator diagrams; flywheels; governors; the simplest forms of steam valves and valve gears.

### PART II.

The Examination in Part II. will be held on Tuesday, May 4th, from 7 till 10.

Candidates will be examined in *one* only of the following four divisions:—

(*A*) Machine drawing and designing. In this examination the candidate will be allowed the use of any one pocket book or treatise on machine designing he may choose to bring with him.

Exercises will be given in drawing simple machine details and in designing them to suit given conditions.

(*B*) Pattern making, moulding, founding and brass founding. Timbers used by pattern makers. Wood-working tools. Building up patterns. Core prints and core boxes. Moulding sand and loam. Moulding tools. Systems of moulding, Parting surfaces. Gates, vents and ladles. Foundry mixtures. Cupolas and crucible furnaces. Brass and gun-metal mixtures.

(*C*) Chipping, filing, turning, drilling, shaping and milling. The grinding and tempering of tools. Cutting speeds. Calculation of change wheels and pulley sizes. Use of measuring instruments, gauges and scribing blocks. Use of surface plates, squares and levels. Construction and use of vices, machine vices and the simpler chucks. Simple engineering workshop appliances.

(*D*) Smithing, forging, riveted and boiler work. Construction of forge. Description of forging and smithing tools. Forms of welded joints. Fluxes used. Hardening and tempering of tools. Annealing and case-hardening. Machine punching and riveting tools. Arrangement of riveted joints. Methods of dealing with overlapping joints. Templets and methods of setting out riveted work.

In Part II. of the examination hand sketches should be used to illustrate the answers; but no credit will be given for these unless they are fairly well drawn and well proportioned, or unless construction is shown by dotting and sectional shading.

### HONOURS GRADE.

*Candidates for Honours must have previously passed in the Ordinary Grade.*

To obtain the certificate in Honours, the Candidate must pass a Written and a Practical Examination, to be taken in the same year.

The fee for the Entire Examination (Written and Practical) is Three Shillings and Sixpence.

The Written Examination will be held on Tuesday, May 4, from 7 till 10.

1. Written Examination.—In the Written Examination on the Mechanics of Engineering candidates must select questions from not more than *two* of the following four divisions :—

(*A*) The elasticity and strength of materials, including the more practical and elementary problems in compound stress. Tension, compression and torsion. Combined bending and torsion. Combined thrust and bending. Riveted joints and the design of riveted work. Collapse. Behaviour of materials when tested. Ordinary limits of working stress.

(*B*) The theory of the steam engine, including the thermodynamics of the action of steam. The solution of problems relating to the simpler valve gears. Governors and flywheels. The theory of gas engines and hot-air engines.

(*C*) Hydraulics and hydraulic motors. Theory of flow from orifices. Flow in pipes. Water wheels, turbines and pumps. Construction and action of valves. Governors for hydraulic machinery. Hydraulic transmission of power. Hydraulic pressure engines. Lifts.

(*D*) Construction of hand and machine tools for engineering workshops. Lifting and other auxiliary appliances in an engineering workshop.

2. Practical Examination.—Candidates will be examined in one division only, either in (*A*) *Machine Designing*, or (*B*) *Workshop Practice.*

(*A*) *Machine Designing.*—Data for a design in Mechanical Engineering will be given at the time of the written examination. The design to be worked out and drawn, and the drawings and a reasoned description of the design, with a summary of calculations of strength, &c., to be returned not later than May 19th with a certificate from some responsible person, other than the candidate, that it has been done without assistance from any other person.

(*B*) *Workshop Practice.*—For candidates selecting this branch of practical work, simple castings or forgings will be sent with dimensioned sketches of the forms to which they are to be worked, by chipping, filing, turning, or screw-cutting. Candidates may be examined in (*a*) Fitters' Work; (*b*) Turning; or (*c*) Pattern-making; and it must be stated on the Application Form which section they select. The work to be executed between given dates and returned with a certificate from the shop foreman * or the class teacher and a member of the School Committee (where the work has been done in a school workshop) that the work has been done without assistance. A candidate may produce, in addition to the exercises set, one piece of work chosen by himself; but he must state the date when it was executed, and the time occupied.

The material for the work will be sent within a week after the written examination, and must be returned, *carriage paid*, to London not later than May 26th.

In the Honours Examination great care should be taken that sketches

* It is hoped that masters will co-operate with the Institute by affording facilities to Candidates in Honours for executing the practical test required in their own workshops. In certain cases where there is a technical school provided with the necessary tools and accommodation, the work can be done in the school workshop.

and drawings are workmanlike and show real knowledge of proportion and construction.

**Full Technological Certificate.**—A Provisional Certificate will be granted on the results of the above Examination. For the full Technological Certificate in the Ordinary Grade, the candidate who is not otherwise qualified (see Rules 40–1) will also be required to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *one* of the following Science subjects:—

| | |
|---|---|
| V. Mathematics. | X. Inorganic Chemistry. |
| VI. Theoretical Mechanics. | XIX. Metallurgy. |

**Works of Reference.**—R. H. Smith's Cutting Tools; Hasluck's Metal Turners' Handbook; Shelley's Workshop Appliances; Compton's First Lessons in Metal Turning; Northcott's Lathes and Turning; Perry's Practical Mechanics; Northcott's Steam Engine; Cotterill's Steam Engine; Ripper's Steam Engine; Seaton's Manual of Marine Engineering; Wilson's Steam Boilers; Robinson's Gas and Petroleum Engines; Unwin's Machine Design; Kennedy's Mechanics of Machinery; Adams' Handbook for Mechanical Engineers; Moray and Biggs' Mechanical Engineering; Holmes' Steam Engine; Article Hydraulics (Encyclopædia Britannica, published separately, price 6s.); Marks' Hydraulic Machinery; Mechanical Engineering, by W. S. Lineham (Chapman & Hall, 10*s*. 6*d*. net).

## 68.—MANUAL TRAINING—METAL WORK.

With the view of certifying to the efficiency of teachers to give instruction in Metal-work, the City and Guilds of London Institute is prepared to issue certificates to qualified teachers of Public Elementary Schools on the following conditions:—

1. Candidates must have already passed the Institute's First Year's Examination in Manual Training—Woodwork.

2. The candidates will be required to give evidence of having regularly attended, during each of two sessions, a course of at least 20 practical metal-working lessons given on separate days, each of not less than two hours' duration, in a school or class registered by, and under an Instructor approved by, the Institute.

   In order that a class may be registered, it must be under the direction of a Committee of a County or Borough Council, or School Board, or Technical School, or other public body.

3. The candidates will further be required to pass two examinations, one at the end of each year's course, to be conducted by examiners appointed by the Institute, and to pay a fee of ten shillings for each examination.

Teachers of Woodwork in Public Elementary Schools (whether Certificated Teachers or not) who give evidence of having satisfactorily taught a class of pupils in Woodwork for a period of not less than one

year, and who produce a certificate from Her Majesty's Inspector or the Inspector of the Local Authority, to that effect, are eligible under the conditions given in paragraph 2, to sit for 1st Year's Examination and subsequently for the Final Examination in Manual Training—Metal-work.

Teachers of Metal-work who give evidence of having satisfactorily taught, for a period of two years, a class of pupils in Metal-work at a Public Elementary School, and who produce a certificate from Her Majesty's Inspector to that effect, are eligible without attendance at any class to sit for the 1st Year's Examination in Manual Training—Metal-work.

## First Year's Examination.

The First Year's Examination will consist chiefly of practical exercises in Metal-work, but candidates will also be required to answer in writing a few simple questions, on the tools used and methods employed in working the exercises of the following syllabus, and on the chief properties of the common metals in their relation to workshop processes.

The exercises for the practical examination will be such as are included in the following syllabus, and candidates should be able to complete any of the exercises mentioned, but they will be required to pass in *two only* of the divisions *A*, *B* and *C*.

*Division A.* Vice Work.—The form and use of flat and cross-cut chisels; flat, round, square and half-round files; scrapers; taps, stocks and dies; screw plates; measuring and other tools, including calipers, square, centre punch, scribing and V-blocks, straight-edges and surface plates. Different forms of vices for bench work, and the grinding and keeping in order of the tools used. Chipping, filing and scraping cast iron, wrought iron, steel, brass and gun-metal to simple forms and given dimensions. Cutting keyways and holes from plates or blocks to fit a given gauge, and preparing and fitting taper and headed key, or other piece. Cutting out and filing up a hexagon or octagon gauge from thin plate, filing and preparing a straight-edge. Drilling, tapping and filing to shape, a square or hexagonal nut; screwing round bar with screw plate and stocks and dies, to fit a given nut.

*Division B.* Bench Work.—Composition of soft solders; use of copper soldering bit; composition and use of ordinary fluxes; soldering simple joints in tin and brass work. The connection of plates and bars, and of joints, with rivets, single and double countersunk, hammered cold.

*Division C.* Forge Work.—The form and use of the ordinary forge tools, management of fire, precautions to be observed in heating metals, drawing out bars to square and round ends, parallel and taper; bending iron to simple curves, or to square or circle of given size; jumping up. Forging of simple examples, as headed key, spike nail, &c.; forging and tempering centre punch, drill and small chipping chisel. Connection of pieces of bar by welding. Case-hardening with prussiate of potash. Annealing.

The examination will be held on two days, on Friday, May 21st, and on Saturday, May 22nd, from 10 till 2, or from 2 till 6 each day.

Provision for holding the Examinations and arrangements for supervision must be made by the Committee of each School. Either tools

must be provided for the Practical Examinations, or the candidates must be required to bring them. Measuring tools (rules, calipers, centre punches, &c.) ought to be brought by candidates.

The special material required for the examination will be supplied by the Institute.

### Final Examination.

Candidates for the Final Examination must produce a certificate of having passed the First Year's examination. They will be required to undergo an examination in practical work, and also a written examination and a drawing examination.

1. Practical Work.—Exercises may be selected from the First Year syllabus *A*, *B* and *C*, only that greater accuracy and finish will be expected; or more difficult exercises of the same character, including examples in brazing, may be set.

Candidates will also be required to work exercises requiring a use of the simple lathe and drilling machine to the following syllabus:—Form and use of hand tools for turning iron and brass; centering of work and fixing in lathe; turning of plain cylindrical rod; simple taper and collar turning; use of V centre for drilling; turning of simple curved pieces to template. Chasing screw threads. Use of slide rest and back gear, and of shifting headstock for taper turning. Methods of screw cutting. Exercises may be set involving forge, vice and lathe work and drilling.

2. Written Examination.—Forms and angles of cutting edges of tools as used for vice and bench work, and for lathes and drilling machines. Construction and use of simple lathes and drilling machines, including the use of change wheels for screw cutting. The working of steam engines and gas engines, and the arrangement of shafting, pulleys and belting, with some knowledge of speed and methods of running, so far as relates to their use for driving purposes in school workshops. The fitting and equipment of a school workshop and arrangement of lessons. Workshop methods and properties of materials, so far as relating to the exercises of the practical examination.

3. Drawing Examination.—Making freehand dimensioned sketches in plan and elevation of hand and machine tools, and other workshop fittings, and of exercises for practical work. Making working drawings to scale, in pencil, from dimensioned sketches.

Candidates must pass in each of the three subjects 1, 2 and 3, in order to obtain a certificate. The practical work will receive four times the marks of either of the other subjects.

Certificates will be granted on the result of each examination, but the Teacher's certificate will be given to those candidates only who have passed the Final Examination.

Provided the necessary arrangements can be made, the Examinations will be held in London and in the Provinces, in the workshops of the Schools where the instruction has been given.

The Examinations for the Final Certificate will be held on the following dates:—

Practical Work. Friday, May 28th, and Saturday, May 29th, from 10 till 2, or from 2 till 6.

Drawing Examination. Wednesday, June 2nd, 7 till 10.

Written Examination. Thursday, June 3rd, 7 till 10.

**Works of Reference.**—Principles of Fitting (Whittaker and Co.); Metal Turning (Whittaker and Co.); Workshop Appliances, by C. P. B. Shelley (Longmans).

# APPENDIX II.

*Session* 1896–97.

## Syllabus of Government Department of Science and Art in

(II.) Machine Construction and Drawing.
(VI.) Theoretical Mechanics.
(VII.) Applied Mechanics.
(XXII.) Steam.

## Subject II.—MACHINE CONSTRUCTION AND DRAWING.

This subject includes a knowledge of the form of the parts of machines, the physical characteristics of the materials used in machine construction, the various workshop processes employed in giving the materials the required shape and size, the magnitude of the straining actions to which they are exposed, and the methods of estimating the dimensions necessary to withstand those straining actions.

In addition to this knowledge, the possession of which may be shown by means of written descriptions, freehand sketches and calculations, a candidate for examination in this subject will be required to be able to draw neatly, to scale, the whole or part of a machine either from dimensioned sketches, which are provided, or from his own design.

### In the Elementary Stage.

A candidate will be required to draw in simple or orthographic projection neatly in pencil to a given scale, two or more views (sectional or outside), of a simple portion of a machine in common use. The sketches from which the drawings are to be produced will be given. They will in general be incomplete, and be drawn purposely somewhat out of proportion, and the candidate will be required to set off, correctly to scale, dimensions, some of which are given on the view he is drawing, the remainder being obtained from the other views. He will be expected to add parts which are omitted from some of the sketches, but shown in shape and size in others. He will further be expected to draw from his own knowledge the fastenings which are suitable for connecting together the machine parts which are the subject of the example, and, in sectional views, to draw lines neatly by freehand to indicate parts cut by the planes of section, taking care to slope the lines on all the parts of the same piece in the same direction, and of contiguous pieces in directions differing from one another.

In some simple cases an additional new view (outside or sectional), which is not shown in the sketches will be required to be drawn, and details which are shown in separate detached sketches will be required to be inserted in their proper places in the general drawing.

The various views required must be placed in position so as to project from one another in order to show that the candidate appreciates the fact that he is producing a representation of a solid piece of machinery and not merely copying a sketch. No credit whatever will be given unless the candidate shows some knowledge of projection by drawing two views of at least one subject in their proper relative situations.

Teachers are enjoined not to rely too much on drawings in giving instruction to their classes, but to make use also of actual simple machine parts or models of them.

It is desirable that centre lines should be shown distinctly, and the parts of other lines continued too far, and not needed in the finished drawing, should be rubbed out.

In order to save time during the examination the drawings should not be inked in, nor should the figured dimensions be inserted.

The following list of examples which have been set in previous years will give a general indication of what may be expected and prepared for:—

*Parts of an Engine.*—Piston. Piston rod end and guide block. Connecting rod. Crank shaft, Excentric and rod. Valve rod end. Simple form of loaded governors.

*Parts of a Boiler.*—Gusset stay. Mud hole door. Water gauge cock. Simple feed pump.

*Portions of Machine Tools.*—Fast headstock and spindle of a lathe. Rest for a hand-tool for a lathe. Jaw of a dog-chuck for a lathe. Quadrant for carrying change wheels for a lathe. Ram of a slotting machine. Parallel jaw vice.

*Mill Work.*—Footstep bearing for an upright shaft. Joint for segments of large spur wheel. Bearing for turbine shaft. Wall bracket.

*General Fittings.*—Hooke's coupling. Ball bearing for a tricycle. Hydraulic pipe joint. Union joint.

Besides making drawings, candidates will be required to answer some of a number of questions on machine construction, and illustrate those answers by sketches. Unless specially instructed to the contrary the sketches should be drawn freehand. The capability of making freehand sketches of parts of machines from memory is of the greatest value to an engineer, and when the sketches are drawn to a tolerable proportion they will be estimated by the examiners at at least as high a value as those drawn more accurately by means of instruments with a much larger expenditure of time.

The details of this portion of the subject may be classified as follows:—

*Formation of Parts of Machines which are in Working Contact:—*

*Journals of Shafts and Bearings.*—Constructions to facilitate adjustment for wear and renewal by cylindrical bushes, cones and brasses, or steps with caps.

Methods of preventing end movement by groove and pin, by collars and by simple forms of footstep or pivot bearings. Joint pin. Knuckle joint. Methods of fixing pin rigidly to the fork portion of the joint.

Simple forms of lubricators.

*Rubbing Surfaces of Sliding Pieces.*—Method of adjustment for wear as in the slide rest of a lathe or other machine tool.

*Helical or Screw Motion.*—Construction of a helical curve. Meaning of the terms pitch and angle of thread.

*Surfaces suitable for Rolling Contact.*—Cylinders, frustums of cones and spheres.

*Surfaces for a Combination of Rolling and Sliding Contact.*—Elementary information relative to the form of spur and bevil wheels.

*Belt Gearing.*—Advantage of a rounded surface. Methods of connecting the ends of a belt.

*Constructions to permit of the Application of the Urging Force and the Working Resistance to the Moving Parts.*—Simple forms of pistons, plungers and stuffing boxes. Use of leather in hydraulic work. Simple forms of slide, lift and screw down valves, and two-way turn cocks.

*Methods of Construction to facilitate the Manufacture of Machine Parts:*—

*Connections*, whereby parts more easily manufactured and more readily renewed when detached, are joined together more or less permanently and rigidly to compose one single piece of a machine. Use of chipping strips.

*Riveted Joints.*—Forms of rivets. Junction of plates by single and double riveting in chain and zig-zag with lap and butt joints. Use of angle, tee and channel irons.

*Bolted Joints.*—Bolts with various forms of heads and nuts. Studs and screws. Use of washers. The Whitworth and square form of screw threads. Raised threads. Methods of preventing nuts from working loose. Prevention of bolts from turning when screwing up the nut. Forms of spanners.

*Cotters.*—Draw of cotter and clearance. Use of gib. Methods of preventing cotters from working loose.

*Flanged Joints* of pipes and cylinders. Methods of making them steam and water tight. Use of a centering ring in a cylinder cover. Union joint for small pipes. Socket joint.

*Construction of the Frame of a Machine.*—Methods of securing frames to foundations. Simple forms of pedestals for supporting a shaft, and methods of attachment to the frame or to a bracket. Simple forms of brackets, hangers and wall boxes.

*Boilers.*—Elementary knowledge of their construction. The methods of uniting the plates. The strengthening of a boiler by the use of bar and gusset stays.

*Primary Pieces.*—Connection of the parts of a shaft. Crank pin to crank arm and arm to shaft. Use of sunk, saddle and feather keys. Methods of withdrawing keys. Box and flange couplings. Connection of the two parts of an excentric sheave, excentric radius, travel of valve. Connection of the parts of sliding pieces. Piston to rod. Rod to cross-head or guide-block, and slide valve to valve rod.

*Secondary Pieces.*—Parts of a connecting rod. Construction of an excentric strap and rod.

*Physical Characteristics of the Common Materials used in Machine Construction.*—Elementary information as to the relative strength, durability under wear, resistance to corrosion, and capability of being cast or forged of iron, steel, brass and copper. Any question which may be set

on the strength and proportions of machine parts will be only of a very elementary character.

*Workshop Processes.*—Elementary information of the processes by which the desired shape is given to machine parts, including the use of the lathe, the planing, shaping, slotting and drilling machines.

### The Advanced Stage.

Will include all that has been detailed for the Elementary Stage.

The examples to be drawn to scale will be a piece of machinery of more complicated construction, requiring the candidate to possess more capability of reading drawings, and the greater part of the drawing required will consist of views not shown, but which will have to be deduced from information given in other views. A greater facility of execution will be expected to be shown by a larger quantity of drawing of a better finish than in the Elementary Stage.

The following is a list of examples which have been set in some previous years:—

*Parts of an Engine.*—Link reversing gear. Regulator valve. Hydraulic engine. Double-ported slide valve.

*Parts of a Boiler.*—Giffard's injector. Safety valve. Double acting pump.

*Mill Work.*—Wall fixing with shafts and bevel wheels. Collar bearing for suspended vertical shaft. To answer the questions a more intimate and detailed knowledge of the parts of machines previously enumerated will be required, and of the following in addition:—

*Formation of Parts of Machines which are in Working Contact.*

*Bearings and Journals of Shafts.*—Methods of completely providing for wear in any direction. Bearings in which the direction of the centre line of the shaft is capable of automatic adjustment. Bearings for working under water; for very high speeds; for locomotive carriages. Construction permitting the use of antifriction soft metal.

*Rubbing Surfaces of Sliding Pieces.*—Use of renewable slipper piece with the guide block of an engine. Automatic lubrication of slides. Guide or valve rods.

*Helical or Screw Motion.*—Screw and nut for transmitting energy. Adjustment for wear of nut.

*Surfaces Suitable for Rolling Contact.*—Methods of keeping in place live rollers used in cranes and heavy revolving pieces.

*Surfaces for a Combination of Rolling and Sliding Contact.*—Simple forms of cams and ratchets. Formation of teeth of wheels. Mortice wheels.

*Belt Gearing.*—Fast and loose pulleys and strap fork arrangements. Length of belt. Rope pulleys. Gearing chains and pulleys.

*Constructions to Permit of the Application of the Urging Force and Working Resistance to the Moving Parts.*—Metallic gland packing. Hydraulic pistons. Pump buckets and valves. Mechanically controlled pump valves. Stop and throttle valves. Arrangements for relieving the pressure on slide valves. Expansion valves for steam engines.

*Methods of Construction to Facilitate the Manufacture of Machine Parts.*

*Riveted Joints.*—Treble riveted joints. Arrangement where three or

more plates overlap. Caulking. Joints in the bars. Connection of parts in girder work. Ordinary proportions of joints and simple calculations of strength.

*Bolted Joints.*—Ordinary proportions of bolts and nuts and simple calculations of strength. Buttress form of screw thread. Foundation and wall bolts and washers. Double ended bolts.

*Cotters.*—Ordinary proportions of steel and iron cotters.

*Flanged Joints* of pipes and cylinders. Diameter and number of bolts. Joints in copper pipes. Expansion joint for steam pipes.

*Construction of the Frame of a Machine in Parts.*—Fixings. Hangers and brackets for carrying pedestals of shafts connected by bevel wheels. Engine beds.

*Boilers.*—Use of bridge or girder stays for strengthening flat surfaces of boilers.

*Primary Pieces.*—Ordinary proportions of keys. Simple forms of disengaging couplings and friction clutches. Methods of constructing fly-wheels, pulleys and spur-wheels in parts.

*Secondary Pieces.*—Forms of section suitable for transmitting a tensile force and a thrust. Form of section suitable for a locomotive coupling rod.

*Physical Characteristics of the common Materials used in Machine Construction.*—Simple questions will be set on the strength and proportions of elementary machine parts and of the pressures at surfaces in working contact.

*Workshop Processes.*—Use of the milling machine. Conditions suitable for its application.

### In the Honours Stage.

The examination is twofold. A paper will be set which may include any question relating to the design, the method of construction, and the use of any machine. As the subject is large, and includes all the various branches of engineering practice, a considerable choice of questions is provided, the candidate being restricted to answering only a limited number. In general about half the questions will be set on the theoretical portion of the subject, and will require a knowledge of how to apply the principles of Applied Mechanics in the calculations relating to machines. This part of the subject will apply equally to the machines employed in all branches of engineering. The other questions will require answers of a descriptive character involving an intimate knowledge of special machines.

Those candidates who answer the questions in this paper in a sufficiently satisfactory way will be permitted to enter for a practical examination which will be held at South Kensington about four weeks after the written examination. *No candidate can be classed in Honours who is not successful in the practical examination.* At the practical examination the candidate will be required to execute a drawing, or design a portion of some machine from given data. In this part of the examination the candidate will in general be allowed the free use of text and note books so that he may to a large extent be working under conditions similar to those which obtain in an engineer's drawing office.

Candidates must themselves provide drawing instruments and all necessary materials, except drawing paper and drawing boards, which will be supplied by the Department.

## Subject VI.—THEORETICAL MECHANICS.

There are two distinct nomenclatures applicable to Subject VI. According to one, the science that investigates the action of force is called mechanics, and is divided into (*a*) statics, treating of the equilibrium of particles and bodies, (*b*) dynamics, treating of the motion of particles and bodies, (*c*) hydrostatics, (*d*) hydrodynamics, treating respectively of the rest and motion of fluids, i.e. liquids and gases. This nomenclature is adopted by many writers of authority, e.g. by Poisson. According to the other, the term dynamics takes the place of mechanics, and the division is into: (i) statics, (ii) kinetics, (iii) hydrostatics, (iv) hydrokinetics. This is a question of words only, but of course one terminology may be better than another. It is, however, to be observed that a considerable number of questions, formerly treated under the head of (*b*) dynamics, relate to motion without reference to the forces producing it. These questions form a distinct branch of pure mathematics to which the name of kinematics is now commonly given. Certain parts of kinematics come into Subject VI., but they occupy a subordinate position in it.

Subject VI. can be taken in two divisions, the first corresponding to (*a*) and (*b*) defined above, the second corresponding with modifications to (*c*) and (*d*). In most cases it would be best for students to take up the first stage, or even first and second stages of the first division, before attempting the second division. However, students have their choice, and to enable them to take up the second division as a separate subject, the syllabus contains several articles which also come into the first division.

In each division there is a first stage, second stage and honour stage. The distinction between the stages is much the same in the two divisions.

In the First Stage the student is required to make himself acquainted with the axioms and the elementary propositions and formulæ of the science, as simple matters of fact, independently of their formal proof. For instance, he must know the proposition called the parallelogram of forces, as a matter of fact, and must be able to apply his knowledge; but he will not be required to prove the proposition. In like manner he will be required to know what is the metacentre of a floating body, but not to prove the formula for finding its position. In a word, he will be required to make brief exact statements, and to work out easy examples. With perhaps an occasional exception, the examples will be either arithmetical, or capable of being answered by an easy construction drawn to scale. No question involving complicated algebra or geometry will be set. The student should be able to substitute numerical values in an algebraical formula, and to solve a simple equation. He should also have accurate notions of ratios. Every student should bring to the examination a pair of compasses, a scale of equal parts and a protractor.

In the Second Stage of either course the student will be concerned with the mathematical treatment of the principles which form the subject of the first stages respectively, so far as the subject can be discussed with the aid of what is generally called elementary mathematics. He should pay particular attention to the proofs of the mechanical propositions referred to in the synopsis of the courses. Thus, he should not merely know that when a particle moves in a circle the force acting towards the

centre is given by the formula $mv^2 \div r$, but he should be able to state the reasoning by which the fact is proved, and to apply his knowledge to a moderately hard example. He should not merely know the rule for finding the magnitude of the resultant pressure of a liquid on a plane area, but be able to state the proof of it.

In the Honours Stage of either course it will be assumed that the student has a fair knowledge of what is commonly understood by the higher mathematics, though in drawing up the questions it will be endeavoured to exclude those which have a merely geometrical or algebraical interest.

It is of course understood that in any stage of either division any question may be asked, which fairly arises out of the contents of any previous stage. It may be added that in all stages the student should bring to the examination the drawing instruments that are necessary for the first stage.

## Division I.

### First Stage or Elementary Course.

1. Units of time and distance; measurement of velocity, whether constant or variable; measurement of acceleration, particularly of constant acceleration; acceleration due to gravity; mass or quantity of matter, unit of mass, density, specific gravity (or specific density); momentum; measurement of force; absolute units of force, particularly the poundal or British absolute unit; distinction between the mass and the weight of a body.

2. Specification of a force. Composition of forces, particularly of two forces, whether acting along intersecting or parallel lines. Equilibrium of two or three forces. Statical couples. Moment of a force. Centre of parallel forces. Work done by a force. Units of work, foot-pound, units of power, horse-power.

3. Different states of matter. Elasticity. Resistance to (1) elongation, (2) compression, (3) bending and (4) torsion.

4. Centre of gravity, and its position in simple cases. Reaction of smooth surfaces, points and hinges. Equilibrium of a body capable of turning on a fixed point or fulcrum. Levers; the steelyard; the balance and its sensibility. Tension of a thread. Pulleys. Equilibrium of a body resting on a smooth plane, horizontal or inclined. Stable and unstable equilibrium.

5. Laws of uniformly accelerated motion, and the formulæ embodying them, viz. $v = V + ft$, $s = Vt + \frac{1}{2} ft^2$, $v^2 = V^2 + 2fs$. Atwood's machine.

6. Composition of two velocities. Uniform motion in a circle; centrifugal force. Small oscillations of a simple pendulum and of a compound pendulum. Convertibility of the centres of oscillation and suspension. Determination of the numerical value of the acceleration due to gravity. Force exerted by the earth on the same mass at different places.

7. Definition of energy. Distinction between potential and kinetic energy. Absolute units of work, particularly the foot-poundal. Equation of work and energy for a constant force acting on a particle.

## Second Stage or Advanced Course.

1. Relative rest and motion. Composition of velocities. Determination of the velocity of a moving point, relatively to another moving point. Angular velocity.

2. Newton's three laws of motion, and his proof of the parallelogram of forces.

3. The composition of forces—including parallel forces and couples—acting in one plane, and the conditions of their equilibrium. Centre of parallel forces.

4. Determination of the centre of gravity in ordinary cases. Properties of the centre of gravity.

5. Friction and laws of friction; co-efficient and angle of friction.

6. Equilibrium of simple machines when friction is not, and when it is, taken into account. Inclined plane, wedge, screw, pulleys. Equilibrium of body resting on axle, whether smooth or rough.

7. Virtual velocities (or virtual work). Stable and unstable equilibrium.

8. Work done by a variable force; diagrams of work in simple cases; the indicator diagram.

9. Rectilinear motion under the action of constant forces, particularly on smooth or rough inclined planes.

10. Motion of projectiles; motion in a circle; motion of a simple pendulum.

11. Impulsive forces. Direct and oblique impact of smooth spheres.

## Honours.

Owing to the great extent of the science of theoretical mechanics, it may be of use to the student to have those parts of the subject marked out to which his attention should, in the first place, be directed. It cannot be too strongly urged on him that the study of the higher branches of mechanics cannot be attempted with advantage unless it is preceded by a thorough knowledge of the elements of the science. The candidate for honours should therefore be prepared to answer readily any question on the advanced course. Supposing this degree of proficiency obtained, his attention should next be directed to the subjects named below, or some of them.

It may be added that there will always be a sufficient number of questions arising out of Nos. 1, 6, 8, of the following articles, and out of Stages 1 and 2, to enable a student to obtain a second class with sound knowledge of these parts of the subjects.

1. The general theory of the composition and resolution of forces, and of the equilibrium of a rigid body. Centre of gravity.

2. Virtual velocities (or virtual work).

3. The equilibrium of flexible, inextensible threads.

4. Simpler cases of the deflection and rupture of beams.

5. The elements of uniplanar kinematics.

6. Moments and products of inertia.

7. General differential equations of the motion of a particle and of a rigid body.

8. Constrained motion of a particle; motion of a rigid body about a fixed axis, including a case when the forces are impulsive.

9. Motion in space of two dimensions.

10. The general principles of dynamics.

## Division II.

### First Stage or Elementary Course.

The subject of Division II. cannot be understood unless the student has a preliminary acquaintance with the fundamental notions of force and motion, on which all parts of the science are based. These are given in Section 1 of the following syllabus. He should also understand what is meant by the resultant of two or more forces, and that in the case of two or more parallel forces the resultant equals the sum of the forces. He should know what is meant by the centre of gravity of a body, some of its elementary properties, and its position in the case of such bodies as sphere, prism, cylinder, circle, parallelogram.

1. Units of time and distance; measurement of velocity, whether constant or variable; measurement of acceleration, particularly of constant acceleration; acceleration due to gravity; mass or quantity of matter, unit of mass, density, specific gravity (or specific density); momentum; measurement of force; absolute units of force, particularly the poundal or British absolute unit; distinction between the mass and the weight of a body.

2. Definition of energy; distinction between potential and kinetic energy; the work done by a force; absolute units of work, particularly the foot-poundal; equation of work and energy for a constant force acting on a particle.

3. Definition of fluid and liquid; transmission of pressure through a fluid; measurement of pressure at any point of a fluid; surface of a liquid acted on by gravity, and pressure at any point within the liquid; distinction between the whole pressure and the resultant pressure of a liquid on a given surface; magnitude and line of action of resultant pressure in the case of a rectangular area, one edge of which is on the surface of the liquid; also in the case of a body wholly or partly immersed in a liquid.

4. Conditions of equilibrium of a floating body; definition of the metacentre; position of a metacentre in the case of a sphere, and of a cylinder with its axis vertical (the formula $4\ \mathrm{HM} . hs = r^2$ being assumed); stability of floatation.

5. Determination of the specific gravity of insoluble solids and of liquids, (1) by the balance, (2) by the specific gravity bottle, (3) by Nicholson's hydrometer; specific gravity of solids lighter than water by the balance; weight of a body in air and in vacuo.

6. Distinction between heat and temperature; definition of higher and lower temperature, and of equal temperature; the mercurial thermometer, and its graduation; Fahrenheit's, the Centigrade and Réaumur's scales. Definition of absolute zero.

7. Air is a heavy elastic fluid; the barometer; pressure of air on the sides of a vessel containing it; variations in this pressure consequent on change of volume and temperature, i.e. Boyle's Law and Dalton's Law, and the formula in which they are embodied, viz. $\mathrm{VP} = \mathrm{CT}$; limitation

of Boyle's law; contents of the "vacuum-space" in barometers of different liquids.

8. Hydrometer of variable immersion; suction-pump; force-pump; siphon; air-pump and mercurial gauge; compressed air manometer; hydraulic press.

## Second Stage or Advanced Course.

The demonstrations and additional subjects of the second stage require corresponding extensions in the preliminary part of the course, as mentioned below. But besides this the student should extend his knowledge of the centre of gravity, and learn how to find the moment of inertia in such simple cases as involve no more than finding the limiting value of $\Sigma_b^a (x^n \Delta x)$ by integration or otherwise, including the case in which $n = -1$.

1. Composition and resolution of forces acting on a body, and the general conditions of their equilibrium. Angular velocity. Uniform circular motion. Work done by a variable force.

2. Resultant pressure of a liquid on an immersed surface plane or curved. Centre of pressure in simple cases. Equilibrium of bodies floating freely or partly supported. Metacentre in simple cases (the formula $HM \cdot V = A k^2$ being assumed). Tension of thin flexible cylinder or sphere under internal fluid pressure.

3. Pressure and elasticity of air; height of the homogeneous atmosphere; variations of the height due to variations of gravity and temperature; pressure of mixed gases; vapours in contact with the liquid producing them; saturation; the dew point; densities of dry and moist air. Work of gas expanding at a constant temperature.

4. Elementary notions of surface tension; rise of a liquid between two plates, and in a capillary tube.

5. Surface of a liquid in a vessel rotating steadily, under the action of gravity; pressure at any point of the liquid.

6. Velocity of liquid issuing from hole in the side of a vessel (Torricelli's Theorem); velocity of the descending surface of the fluid.

7. Elementary notions of the propagation of an aerial disturbance along a straight tube; geometrical representation of the motion of the aerial particles constituting a wave; explanation of the interference of two waves; corresponding representation and explanation by means of a sine function (e.g. $A \sin (n t + \beta)$).

## Honours.

The parts of this course are to some extent alternative. The student will be at liberty to answer questions in any part of the paper, but it will be possible for him to obtain a first class by answering questions arising out of previous stages, and out of the first six or out of the last four of the following articles. The honours stage consists in great part of the subjects of the previous stages, but treated more generally.

1. General conditions of the equilibrium of fluids acted on by any forces.

2. Resultant pressure of a liquid on plane and curved surfaces.

3. Centre of pressure of a plane area.

4. Condition of stability of floatation in respect of small displacements.

5. Stability of floatation when the displacement is large.

6. Formula for finding distances of altitude by the barometer and the necessary corrections.

7. Sudden compression and expansion of gases; ratio of specific heat of air at constant pressure to specific heat of air at constant volume.

8. Motion of aerial waves in a straight tube; investigation and integration of the equation $\frac{d^2 z}{d t^2} = a^2 \frac{d^2 z}{d x^2}$, and interpretation of results.

9. Elements of the kinetic theory of gases.

## Subject VII.—APPLIED MECHANICS.

In order to prepare for this examination the student should carefully inform himself as to the details and construction of the various contrivances, machines and appliances, referred to in the list given below; and in doing so, he must seek to understand the manner in which certain natural laws or mechanical principles receive their useful application.

The list for the first stage is necessarily comprehensive, but the questions will be framed in such a manner that a candidate who has obtained a fair knowledge of a portion only of the subjects may hope to pass with some credit. Easy questions involving arithmetical results may arise, and in particular the student should be able to solve simple mechanical problems by graphic construction. The list for the second stage refers also to a wide range of subjects, and he will be liable to questions involving only a very limited knowledge of mathematics.

In the honours paper a fair amount of mathematical knowledge may be required.

### First Stage or Elementary Course.

The subjects for examination will be:—

*Measurement.*—Line and end measure. Rules, callipers, gauges.

*True Plane Surfaces.*—Surface plates. Method of surfacing. Applications in machinery.

*The principle of Work and its Application to simple Machines.*—Levers. Balances. Safety valves. Pulleys. The snatchblock. Sheaves. The inclined plane. Screws, forms of thread, mechanical characteristics of screw threads. Right and left handed screws, single and double threaded screws. The screw and lever in combination. Screw presses. Lifting jacks. Endless screw and worm-wheel. Wheel and axle, its applications. Winch or crab. Power gained by wheelwork.

*The Conversion of Motion.*—Endless bands, straps, fast and loose pulleys, guide pulleys. Toothed wheels. Rack and pinion. The crank and connecting rod. Cams. Mangle motions. Ratchet wheels, detents.

*Special Contrivances.*—Such as:—The fusee. The wheel and compound axle. Weston's pulley block. Escapements. Geneva stop. Fast and slow motion in the headstock of a lathe.

*Energy.*—What it means. The measure of work stored up in a raised weight or in a heavy mass in motion. The fly-wheel. Fly-presses.

*The Pressure of Water.*—Estimation of water pressure on plane surfaces such as sluice gates. Pressure gauges. The hydrostatic press. The accumulator, or vessel for obtaining a supply of water under pressure.

*Machines for Raising Water.*—Pumps. Lift pumps. Force pumps. The use of an air vessel.

*Materials.*—Iron; qualities required for different purposes. Testing of iron for strength and ductility. Steel; hardening and tempering. Copper and tin; their alloys. Gun-metal. Brass.

*Strength of Materials.*—Power of resistance of different materials to tensile and compressive stresses. Power of resistance to forces acting transversely. Influence of form or dimensions of section. Influence of length, of position of load, of distribution of load.

*Friction.*—The laws of friction. Contrivances for lessening the effect of friction.

In answering the questions, students will be required to make hand sketches of the details of the various parts in a clear and intelligible manner. Great importance will be attached to this requirement.

## Second Stage or Advanced Course.

The subjects for examination will include everything mentioned in the first course, but candidates will be expected to possess a more extended and thorough knowledge of the various details, as well as of theoretical principles.

The additional matter will be the following:—

*Miscellaneous Details.*—The forging of iron. Welding. The casting of iron. Moulding. Soldering. Brazing. The expansion and contraction of metals.

*Friction.*—Examples where friction is useful. Rolling friction. Brakes. Strap-brakes. Friction and other dynamometers. The efficiency of machines. Friction grips. Holding power of ropes when coiled. Friction clutches.

*Strength of Materials.*—Estimation of stresses in a rectangular timber beam. Cast and wrought iron girders. Cantilevers. Buckled plates. The deflection of beams.

*Stressses in Framework.*—Simple examples of framework, with corresponding diagrams of stress. Travellers, roofs. Lattice girders. Trussed beams.

*Shearing Stresses.*—Cotters, rivets, joints of plates. Strength of shafting to resist torsion. Hollow or solid shafting.

*Compressive Stress.*—Pillars. Piers. T and angle iron struts. Tie-bars.

*The Conversion of Motion.*—Quick return movements. Linkwork and parallel motions. Peaucellier's invention. Trains of wheels for screw-cutting, clockwork. Epicyclic trains. Rope-making machinery. Differential motion of three bevil wheels. Universal joints.

*Pressure of Air.*—Fans, blowers, air pumps. Gauges for measuring the pressure of air. Construction and efficiency of windmills. The diving-bell.

*Hydraulic Machines.*—Water wheels. Forms of buckets. Pendulum governor for water wheels. Turbines. Centrifugal pumps. Hydraulic press. The hydraulic jack. Hydraulic cranes, different powers. Force pump for feeding the accumulator. The water ram.

*Description of Machines in Common Use.*—Such as:—Cranes. Machines for weighing. Counting and numbering machines. Corn mills. Clocks. Dead beat escapement. The lever escapement. The chronometer escapement. The keyless watch. Hand printing presses.

*Principles and construction of Hand Tools.*—Such as:—Chisels. Planes. Gimlets. Augers. Saws. Drills. Files.

*Machine Tools.*—Such as:—Lathes, ordinary and screw cutting. Planing, shaping and slotting machines. Reversing motions. Drilling and boring machines. Punching and shearing machines. Feed motions.

The observations already made with reference to hand sketching apply equally here, and details of machines, such as feed motions, reversing motions, &c., might form the subject of questions, the answers to which will be of no value unless the sketches are correctly given.

### Honours.

The above syllabus will sufficiently indicate the nature of the subjects that form the basis for the examination in honours. Candidates must be versed in mechanical principles, and will be asked to give theoretical investigations which may bear upon the subject matter under consideration.

## Subject XXII.—STEAM.

### First Stage or Elementary Course.

Students in this course will be required to possess some knowledge of the effects of heat on matter, such as changes of temperature, expansion, change of elasticity, vaporisation, liquefaction; they must also know something of the phenomena of the radiation, absorption, conduction and convection of heat; they will be liable to questions relating to the mechanical equivalent of heat, as well as to the conversion of work into heat and of heat into work; they must also inform themselves on the following subjects, viz. the causes which influence the boiling temperature of water, the boiling points of fresh and salt water, high pressure steam, measure of steam pressure by atmospheres, the relation between the pressure, density and temperature of steam, the specific volume of steam, the latent heat of steam, the quantity of water required to produce condensation, the distinction between saturated and superheated steam.

*Early Engines.*—Newcomen's atmospheric engine, its defects. The discoveries of Watt. Hornblower's compound engine.

*The Single-acting Condensing Pumping Engine.*—Details connected with this engine; the steam cylinder, the steam, equilibrium and eduction valves, their action; the steam-jacket, the clothing of the cylinder; the condenser, the air-pump, the foot-valve, the delivery-valve.

the snifting valve, the hot well; the piston rod, stuffing boxes and glands; the construction of the beam in large engines, the plug rod, the parallel motion; the method of starting the engine, and of regulating its speed, the construction and action of the cataract.

*Double-acting Condensing Engine.*—Details of the various parts, the cylinder, how constructed, the ports or openings into the cylinder; the various forms of valves in common use, the methods of balancing valves, the three-ported valve, the lap on a valve, the lead of a valve, the eccentric; details of the piston, metallic packing rings; the air-pump, jet condenser, the surface condenser, gauges for the condenser, the barometer gauge, method of estimating pressure by it, errors in this method, and correction of the same; the crank and connecting rod, the strap, gib and cotter, the beam, parallel motion in beam engines, the governor, the fly-wheel; stopping and starting gear. Various types of direct-acting condensing engines.

*The Non-condensing Engine.*—Various types of direct-acting engines.

*The Expansion of Steam.*—Saturated and super-heated steam; law of expansion; the object of expanding steam; modes of carrying out expansive working. Expansion valves; double beat valve, crown valve, gridiron valve; wire drawing of steam, the throttle valve.

*Stationary Boilers.*—The Cornish boiler, the Lancashire boiler, the vertical boiler; heating and fire-grate surfaces, the evaporative power of boilers, boiler chimneys: the strength of boilers, the use of stays, the proving of boilers. Boiler appendages; safety valves, reverse or atmospheric valves, communication or stop valves; the glass water gauge, steam pressure gauge, various forms, the heating of feed water, feed pumps. Priming, its causes and remedies.

*The Marine Steam Engine.*—Various types of paddle-wheel engines; the oscillating and inclined engine, various types of screw propeller engines. Details of parts connected with the working of marine engines, expansion and reversing gear; bilge and feed pumps.

*Marine Boilers.*—General forms and construction; tubes and flues; the funnel and its casing; fire-bridge and ashpit, waste steam pipe, water gauge, gauge cocks, pressure gauges, safety valves, reverse valves, stop valves, feed pumps, boiler hand-pump; feed or donkey-engine; Kingston's valves, blow-out cocks, brine-pumps and brine-valves; the methods of ascertaining the degree of saltness of the water in a boiler, amount of saltness permissible; formation of scale; superheating apparatus; surface condensation.

*The Locomotive Engine.*—The general construction of a locomotive engine and boiler before the invention of Stephenson; description of the Rocket engine as the type of the modern locomotive, the tubular boiler, the draught produced by the discharge of waste steam.

*Details.*—Inside cylinders, outside cylinders, steamways, ports, slide valve; water cocks, grease cocks, the piston and packing-rings, piston-rod, guides, connecting rod, eccentrics, the reversing or link motion, reversing lever, sector, expansive working; crank axle and driving wheels, power required for traction, adhesion of the driving wheels, counter weights to cranks, wheels and axles, axle-boxes, bearing-springs, buffer and draw springs, friction brakes.

*The Boiler.*—The fire-box, the inner and outer shell, the cylindrical barrel, the tubes, mode of fixing them, fire-box stays, gusset stays; the

ash-pit, the smoke box, the blast pipe, mechanical action of the blast; the steam chest, the outer dome, the steam pipe, the regulator, safety valves, pressure gauges; whistles, blow-off cocks, feed pumps, Giffard's injector; evaporative power of the boiler, fire-grate and heating surface, combustion of fuel; the tender, water-tank, tank-engines, brake, feed pipes; coke-burning engines, methods of consuming smoke in coal-burning engines. Ramsbottom's method of filling the tender.

In this examination it is essential that the student should acquire the power of making hand sketches of the various parts which he may be called upon to describe. The observations made in the syllabus for Applied Mechanics hold equally in this subject, and it is further to be noted that the student is liable to be questioned as to the mechanical principles involved in any of the matters herein mentioned.

## Second Stage or Advanced Course.

Students will be examined in the subjects already set forth, but will be expected to show a more extended knowledge of the same, and they should now be prepared also to answer questions in accordance with the second part of the syllabus as follows:—

*Valves and Valve Gears.*—Various types of valves, the double and treble ported, the piston, the Trick, and other valves. Meyer's expansion valve. The position of eccentrics on the crank-shaft; Zeuner's valve diagrams; effect of length of rod in modifying steam distribution. The valve motions or gears of Stephenson, Hackworth, Marshall, Corliss, Joy, and others. Expansion valves for compound engines. The distribution of steam in various types of compound engines.

*Condensation.*—Surface and jet condensers. Extent of surface required in surface condensers. Amount of water necessary for the condensation of steam. Construction of air pumps and circulation pumps. Ejector condensers.

*Compound Engines.*—Various types of compound engines, triple and quadruple expansion engines. Webb's compound locomotive engine.

*Fly-Wheel and Governors.*—Theory of their action. Proper diameter and weight for fly-wheels, details of construction of the fly-wheel. Construction and action of Watt's pendulum governor, of the Porter governor, and of other high speed governors. The parabolic governor.

*The Indicator.*—Description of the instrument, the atmospheric line. Method of taking a diagram. The general configuration of diagram to be expected under various circumstances. Examination of the indicator diagram when the steam is throttled; when expansive gear alone used, and in other cases. To ascertain the horse-power of an engine by means of the indicator. The indicator diagram in engines of various types. The combining of the indicator cards of a compound engine.

*Propellers.*—Paddle wheels, feathering of the floats, disconnection and immersion of wheels. The screw propeller, various forms, length, angle, pitch and area of screw blade, disconnecting and raising the screw; the position of the screw propeller in the vessel, twin screws, the slip of the screw; the method of receiving the thrust upon the vessel, soft metal and hard wood bearings.

*Theoretical Portion.*—Work done during the conversion of water into

steam; work done in a steam cylinder when the steam is expanded; work done in the air-pump; work developed by a crank; inertia of reciprocating parts, diagram of crank pin effort. Method of measuring the efficiency of a steam engine; meaning of absolute temperature; isothermal and adiabatic curves; efficiency of heat engines; experimental testing of engines; estimation of loss of fuel by "blowing out"; calculations relating to parallel motions, such as Watt's and Peaucellier's; estimation of the relative positions of the piston and crank in any part of the stroke; diagram showing the relative motions of the slide and piston; dynamometer, its use in finding the horse-power of an engine.

In order to encourage the study of the gas engine some questions will be set in the advanced course, which will embrace the following subject-matter; but these questions will not be compulsory.

*Hot-air and Gas Engines.*—General principles underlying the action of such engines. Stirling's hot-air engine; the regenerator; the construction of refrigerating machines. The efficiency of air engines. Explosive mixtures of gas and air. The Lenoir engine. The Otto engine. Details of construction of the Otto engine. The valves required, their construction and action. The charging of the cylinder. The firing of the charge. Mechanism for operating the valves, for regulating the speed, and for admitting the gas. Fittings of the engine. The cycle of operations. The indicator diagram. The efficiency of the engine.

## HONOURS.

The range of subjects will comprise the whole syllabus, and students will be expected to show a more extended knowledge, both in a theoretical and practical direction, than is required of them in the second stage.

# APPENDIX III.

## Syllabus of the City of London College Engineering Department.

Subject to revision annually, ready first week in September, and forwarded gratis on application to the Secretary, City of London College, White Street, Moorfields, London, E.C.

# INDEX.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

# BOOKS RELATING

TO

# APPLIED SCIENCE

PUBLISHED BY

## E. & F. N. SPON, LIMITED.

LONDON: 125 STRAND.

NEW YORK: SPON & CHAMBERLAIN.

**Algebra.**—*Algebra Self-Taught.* By W. P. HIGGS, M.A., D.Sc., LL.D., Assoc. Inst. C.E., Author of 'A Handbook of the Differential Calculus,' etc. Second edition, crown 8vo, cloth, 2*s.* 6*d.*

CONTENTS:

Symbols and the Signs of Operation—The Equation and the Unknown Quantity—Positive and Negative Quantities—Multiplication—Involution—Exponents—Negative Exponents—Roots, and the Use of Exponents as Logarithms—Logarithms—Tables of Logarithms and Proportionate Parts—Transformation of System of Logarithms—Common Uses of Common Logarithms—Compound Multiplication and the Binomial Theorem—Division, Fractions, and Ratio—Continued Proportion—The Series and the Summation of the Series—Limit of Series—Square and Cube Roots—Equations—List of Formulæ, etc.

**Architects' Handbook.**—*A Handbook of Formulæ, Tables and Memoranda, for Architectural Surveyors and others engaged in Building.* By J. T. HURST, C.E. Fourteenth edition, royal 32mo, roan, 5*s.*

"It is no disparagement to the many excellent publications we refer to, to say that in our opinion this little pocket-book of Hurst's is the very best of them all, without any exception. It would be useless to attempt a recapitulation of the contents, for it appears to contain almost *everything* that anyone connected with building could require, and, best of all, made up in a compact form for carrying in the pocket, measuring only 5 in. by 3 in., and about ¾ in. thick, in a limp cover. We congratulate the author on the success of his laborious and practically compiled little book, which has received unqualified and deserved praise from every professional person to whom we have shown it."—*The Dublin Builder.*

**Architecture.**—*The Seven Periods of English Architecture,* defined and illustrated. By EDMUND SHARPE, M.A., Architect. 20 *steel engravings and* 7 *woodcuts*, third edition, royal 8vo, cloth, 12*s.* 6*d.*

**Baths.**—*The Turkish Bath*: its Design and Construction for Public and Commercial Purposes. By R. O. ALLSOP, Architect. *With plans and sections*, 8vo, cloth, 6*s*.

**Baths and Wash Houses.**—*Public Baths and Wash Houses*. By ROBERT OWEN ALLSOP, Architect, Author of 'The Turkish Bath,' &c. *With cuts and folding plates*, demy 8vo, cloth, 6*s*.

**Belting.**—*Belt Driving*. By GEORGE HALLIDAY, Whitworth Scholar. *With plates*, 8vo, cloth, 3*s*. 6*d*.

CONTENTS:

Description of different Kinds of Belts—Pressure transmitted by Belts—Length of Belt and Coned Pulleys—Stretching of Belts—V Pulleys—Arms of Pulleys—Methods of Use of the Belt discussed—Rope Gearing—Tables—Rules for finding the Pitch of Spur-Wheels.

**Blasting.**—*Rock Blasting*: a Practical Treatise on the means employed in Blasting Rocks for Industrial Purposes. By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. *With* 56 *illustrations and* 12 *plates*, 8vo, cloth, 5*s*.

**Boilers.**—*A Pocket-Book for Boiler Makers and Steam Users*, comprising a variety of useful information for Employer and Workman, Government Inspectors, Board of Trade Surveyors, Engineers in charge of Works and Slips, Foremen of Manufactories, and the general Steam-using Public. By MAURICE JOHN SEXTON. Fourth edition, enlarged, royal 32mo, roan, gilt edges, 5*s*.

**Boilers.**—*The Boiler-Maker's & Iron Ship-Builder's Companion*, comprising a series of original and carefully calculated tables, of the utmost utility to persons interested in the iron trades. By JAMES FODEN, author of 'Mechanical Tables,' etc. Second edition, revised, *with illustrations*, crown 8vo, cloth, 5*s*.

**Brass Founding.**—*The Practical Brass and Iron-Founder's Guide*, a Treatise on the Art of Brass Founding, Moulding, the Metals and their Alloys, etc. By JAMES LARKIN. New edition, revised and greatly enlarged, crown 8vo, cloth, 10*s*. 6*d*.

**Breweries.**—*Breweries and Maltings*: their Arrangement, Construction, Machinery, and Plant. By G. SCAMELL, F.R.I.B.A. Second edition, revised, enlarged, and partly rewritten. By F. COLYER, M.I.C.E., M.I.M.E. *With* 20 *plates*, 8vo, cloth, 12*s*. 6*d*.

**Bridges.**—*Elementary Theory and Calculation of Iron Bridges and Roofs*. By AUGUST RITTER, Ph.D., Professor at the Polytechnic School at Aix-la-Chapelle. Translated from the third German edition, by H. R. SANKEY, Capt. R.E. *With* 500 *illustrations*, 8vo, cloth, 15*s*.

**Bridges.**—*Plate Girder Railway Bridges.* By MAURICE FITZMAURICE, B.A., B.E., Mem. Inst. C.E. *Plates*, 8vo, cloth. 6*s*.

CONTENTS:

Formulæ and Tables of Loads and Weights for Plate Girder Bridges, with Remarks on the allowable Working Stresses to be adopted in Steel and Iron—The Market sizes of Plates and Bars, and the different kinds of Bridge floors, with examples worked out in detail.

**Bridges.**—*Stresses in Girder and Roof Trusses for both Dead and Live Loads by Simple Multiplication*, with Stress Constants for 100 cases, for the use of Civil and Mechanical Engineers, Architects and Draughtsmen. By F. R. JOHNSON, Assoc. M. Inst. C.E. Part 1, Girders. Part 2, Roofs. In 1 vol., crown 8vo, cloth, 6*s*.

**Builders' Price Book.**—*Spons' Architects' and Builders' Price Book, with useful Memoranda.* By W. YOUNG. Crown 8vo, cloth, red edges, 3*s*. 6*d*. *Published annually.*

**Building.**—*The Clerk of Works:* a Vade-Mecum for all engaged in the Superintendence of Building Operations. By G. G. HOSKINS, F.R.I.B.A. Sixth edition, fcap. 8vo, cloth, 1*s*. 6*d*.

**Building.**—*The Builder's Clerk:* a Guide to the Management of a Builder's Business. By THOMAS BALES. Fcap. 8vo, cloth, 1*s*. 6*d*.

**Calculus.**—*An Elementary Treatise on the Calculus for Engineering Students*, with numerous Examples and Problems worked out. By JOHN GRAHAM, B.A., B.E., Demonstrator and Instructor in Mathematics in the City and Guilds of London Technical College, Finsbury. Crown 8vo, cloth, 7*s*. 6*d*.

**Canals.**—*Waterways and Water Transport in Different Countries.* With a description of the Panama, Suez, Manchester, Nicaraguan, and other Canals. By J. STEPHEN JEANS, Author of 'England's Supremacy,' 'Railway Problems,' &c. *Numerous illustrations*, 8vo, cloth, 14*s*.

**Carpentry.**—*The Elementary Principles of Carpentry.* By THOMAS TREDGOLD. Revised from the original edition, and partly re-written, by JOHN THOMAS HURST. Contained in 517 pages of letterpress, and *illustrated with* 48 *plates and* 150 *wood engravings.* Sixth edition, reprinted from the third, crown 8vo, cloth, 12*s*. 6*d*.

Section I. On the Equality and Distribution of Forces—Section II. Resistance of Timber—Section III. Construction of Floors—Section IV. Construction of Roofs—Section V. Construction of Domes and Cupolas—Section VI. Construction of Partitions—Section VII. Scaffolds, Staging, and Gantries—Section VIII. Construction of Centres for Bridges—Section IX. Coffer-dams, Shoring, and Strutting—Section X. Wooden Bridges and Viaducts—Section XI. Joints, Straps, and other Fastenings—Section XII. Timber.

**Chemistry.**—*Practical Work in Organic Chemistry.* By F. W. STREATFEILD, F.I.C., etc., Demonstrator of Chemistry at the City and Guilds of London Institutes Technical College, Finsbury. With a Prefatory Notice by Professor R. MELDOLA, F.R.S., F.I.C. Crown 8vo, cloth, 3*s.*

**Chemists' Pocket Book.**—*A Pocket-Book for Chemists, Chemical Manufacturers, Metallurgists, Dyers, Distillers, Brewers, Sugar Refiners, Photographers, Students, etc., etc.* By THOMAS BAYLEY, Assoc. R.C. Sc. Ireland, Analytical and Consulting Chemist and Assayer. Fifth edition, 481 pp., royal 32mo, roan, gilt edges, 5*s.*

SYNOPSIS OF CONTENTS:

Atomic Weights and Factors—Useful Data—Chemical Calculations—Rules for Indirect Analysis—Weights and Measures—Thermometers and Barometers—Chemical Physics—Boiling Points, etc.—Solubility of Substances—Methods of Obtaining Specific Gravity—Conversion of Hydrometers—Strength of Solutions by Specific Gravity—Analysis—Gas Analysis—Water Analysis—Qualitative Analysis and Reactions—Volumetric Analysis—Manipulation—Mineralogy—Assaying—Alcohol—Beer—Sugar—Miscellaneous Technological matter relating to Potash, Soda, Sulphuric Acid, Chlorine, Tar Products, Petroleum, Milk, Tallow, Photography, Prices, Wages, Appendix, etc., etc.

**Coffee Cultivation.**—*Coffee: its Culture and Commerce in all Countries.* Edited by C. G. WARNFORD LOCK, F.L.S. Crown 8vo, cloth, 12*s.* 6*d.*

A practical handbook for the Planter, treating in a thoroughly practical manner on the cultivation of the Plant, the management of an estate, Diseases and enemies of the Coffee Plant (with their prevention and cure), preparation of the berry for market, and statistics of local details of culture and production. Bibliography.

**Concrete.**—*Notes on Concrete and Works in Concrete;* especially written to assist those engaged upon Public Works. By JOHN NEWMAN, Assoc. Mem. Inst. C.E. Second edition, revised and enlarged, crown 8vo, cloth, 6*s.*

**Coppersmithing.**—*Art of Coppersmithing:* a Practical Treatise on Working Sheet Copper into all Forms. By JOHN FULLER, Sen. *Numerous engravings*, illustrating almost every branch of the Art. Royal 8vo, cloth, 12*s.* 6*d.*

**Corrosion.**—*Metallic Structures: Corrosion and Fouling, and their Prevention;* a Practical Aid-Book to the safety of works in Iron and Steel, and of Ships; and to the selection of Paints for them. By JOHN NEWMAN, Assoc. M. Inst. C E., F. Impl. Inst., Author of 'Notes on Concrete,' &c., &c. Crown 8vo, cloth, 9*s.*

**Depreciation of Factories.**—*The Depreciation of Factories and their Valuation.* By EWING MATHESON, Mem. Inst. C.E. Second edition, revised, with an Introduction by W. C. JACKSON, Member of the Council of the Institute of Chartered Accountants. 8vo, cloth, 7*s.* 6*d.*

Drainage.—*The Drainage of Fens and Low Lands by Gravitation and Steam Power.* By W. H. WHEELER, M. Inst. C.E. *With plates*, 8vo, cloth, 12*s.* 6*d.*

Drawing,—*Hints on Architectural Draughtsmanship.* By G. W. TUXFORD HALLATT. Fcap. 8vo, cloth, 1*s.* 6*d.*

Drawing.—*The Draughtsman's Handbook of Plan and Map Drawing;* including instructions for the preparation of Engineering, Architectural, and Mechanical Drawings. *With numerous illustrations in the text, and* 33 *plates* (15 *printed in colours*). By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. 4to, cloth, 9*s.*

Drawing Instruments.—*A Descriptive Treatise on Mathematical Drawing Instruments:* their construction, uses, qualities, selection, preservation, and suggestions for improvements, with hints upon Drawing and Colouring. By W. F. STANLEY, M.R.I. Sixth edition, *with numerous illustrations*, crown 8vo, cloth, 5*s.*

Dynamo.—*Dynamo-Tenders' Hand-Book.* By F. B. BADT. *With* 70 *illustrations.* Third edition, 18mo, cloth, 4*s.* 6*d.*

Dynamo-Electric Machinery.—*Dynamo-Electric Machinery:* a Text-Book for Students of Electro-Technology. By SILVANUS P. THOMPSON, B.A., D.Sc. Fifth edition, 8vo, cloth, 24*s.*

Earthwork Slips.—*Earthwork Slips and Subsidences upon Public Works:* Their Causes, Prevention and Reparation. Especially written to assist those engaged in the Construction or Maintenance of Railways, Docks, Canals, Waterworks, River Banks, Reclamation Embankments, Drainage Works, &c., &c. By JOHN NEWMAN, Assoc. Mem. Inst. C.E., Author of 'Notes on Concrete,' &c. Crown 8vo, cloth, 7*s.* 6*d.*

Electric Lighting.—*Electric Lighting: a Practical Exposition of the Art*, for the use of Engineers, Students, and others interested in the Installation and Operation of Electrical Plant. Vol. I. The Generating Plant. By FRANCIS B. CROCKER, E.M., Ph.D., Professor of Electrical Engineering in Columbia University, New York. *With* 152 *illustrations.* 8vo. cloth, 12*s.* 6*d.*

Electric Bells.—*Electric Bell Construction:* a treatise on the construction of Electric Bells, Indicators, and similar apparatus. By F. C. ALLSOP, Author of 'Practical Electric Bell Fitting. *With* 177 *illustrations drawn to scale*, crown 8vo, cloth, 3*s.* 6*d.*

**Electric Bells.**—*A Practical Treatise on the fitting up and maintenance of Electric Bells and all the necessary apparatus.* By F. C. ALLSOP, Author of 'Telephones, their Construction and Fitting.' Second edition, revised, *nearly* 150 *illustrations*, crown 8vo, cloth, 3*s*. 6*d*.

**Electric Currents.**—*Polyphase Electric Currents and Alternate Current Motors.* By SILVANUS P. THOMPSON, B.A., D.Sc., M. Inst. E.E., F.R.S. *Numerous cuts and plates*, demy 8vo, cloth, 12*s*. 6*d*.

**Electric Lighting.**—*Wrinkles in Electric Lighting.* By VINCENT STEPHEN. *With illustrations.* 18mo, cloth, 2*s*. 6*d*.

CONTENTS:

1. The Electric Current and its production by Chemical means—2. Production of Electric Currents by Mechanical means—3. Dynamo-Electric Machines—4. Electric Lamps—5. Lead—6. Ship Lighting.

**Electric Telegraph.** — *Telegraphic Connections,* embracing recent methods in Quadruplex Telegraphy. By CHARLES THOM and WILLIS H. JONES. *With illustrations.* Oblong 8vo, cloth, 7*s*. 6*d*.

**Electric Testing.**—*A Guide for the Electric Testing of Telegraph Cables.* By Col. V. HOSKIŒR, Royal Danish Engineers. Third edition, crown 8vo, cloth, 4*s*. 6*d*.

**Electric Toys.**—*Electric Toys.* Electric Toy-Making, Dynamo Building and Electric Motor Construction for Amateurs. By T. O'CONOR SLOANE, Ph.D. *With cuts*, crown 8vo, cloth, 4*s*. 6*d*.

**Electrical Notes.**—*Practical Electrical Notes and Definitions for the use of Engineering Students and Practical Men.* By W. PERREN MAYCOCK, Assoc. M. Inst. E.E., Instructor in Electrical Engineering at the Pitlake Institute, Croydon, together with the Rules and Regulations to be observed in Electrical Installation Work. Second edition. Royal 32mo, cloth, red edges, 2*s*.

**Electrical Tables.**—*Electrical Tables and Memoranda.* By SILVANUS P. THOMPSON, D.Sc., B.A., F.R.S., and EUSTACE THOMAS. In waistcoat-pocket size (2½ in. by 1¾ in.), French morocco, gilt edges, *with numerous illustrations*, 1*s*.

**Electricity.** — *The Arithmetic of Electricity;* Manual of Electrical Calculations by Arithmetical Methods. By T. O'CONOR SLOANE, Ph.D. Crown 8vo, cloth, 4*s*. 6*d*.

**Electrical Testing.**—*A Handbook of Electrical Testing.* By H. R. KEMPE, M.I.E.E. Fourth edition, revised and enlarged, 8vo, cloth, 18*s.*

**Electrical Testing.**—*A Practical Guide to the Testing of Insulated Wires and Cables.* By HERBERT LAWS WEBB, Member of the American Institute of Electrical Engineers, and of the Institution of Electrical Engineers, London. Crown 8vo, cloth, 4*s.* 6*d.*

**Electricity.**—*Short Lectures to Electrical Artisans,* being a Course of Experimental Lectures delivered to a practical audience. By J. A. FLEMING, M.A., D.Sc. (Lond.), Professor of Electrical Technology in University College, London. *With diagrams,* fourth edition, crown 8vo, cloth, 4*s.*

**Electricity.**—*Electricity, its Theory, Sources, and Applications.* By JOHN T. SPRAGUE, M. Inst. E.E. Third edition, thoroughly revised and extended, *with numerous illustrations and tables,* crown 8vo, cloth, 15*s.*

**Electricity in the House.**—*Domestic Electricity for Amateurs.* Translated from the French of E. HOSPITALIER, Editor of 'L'Electricien,' by C. J. WHARTON, M. Inst. E.E. *Numerous illustrations.* Demy 8vo, cloth, 6*s.*

CONTENTS:

1. Production of the Electric Current—2. Electric Bells—3. Automatic Alarms—4. Domestic Telephones—5. Electric Clocks—6. Electric Lighters—7. Domestic Electric Lighting—8. Domestic Application of the Electric Light—9. Electric Motors—10. Electrical Locomotion—11. Electrotyping, Plating, and Gilding—12. Electric Recreations—13. Various applications—Workshop of the Electrician.

**Electricity on Railways.**—*The Application of Electricity to Railway Working.* By W. E. LANGDON, M. Inst. E.E., Superintendent Electrical Department, Midland Railway. *With* 142 *illustrations.* 8vo, cloth, 10*s.* 6*d.*

**Electro-Magnet.**—*The Electro-Magnet and Electromagnetic Mechanism.* By SILVANUS P. THOMPSON, D.Sc., F.R.S. *With* 213 *illustrations.* Second edition, 8vo, cloth, 15*s.*

**Electro-Motors.**—*Notes on design of Small Dynamo.* By GEO. HALLIDAY, Whitworth Scholar, Professor of Engineering at the Hartley Institute, Southampton. *Plates,* 8vo, cloth, 2*s.* 6*d.*

**Electro-Motors.**—*The practical management of Dynamos and Motors.* By FRANCIS B. CROCKER, Professor of Electrical Engineering, Columbia College, New York, and SCHUYLER S. WHEELER, D.Sc. *Cuts,* crown 8vo, cloth, 4*s.* 6*d.*

**Engineering Drawing.** — *Practical Geometry, Perspective and Engineering Drawing*; a Course of Descriptive Geometry adapted to the Requirements of the Engineering Draughtsman, including the determination of cast shadows and Isometric Projection, each chapter being followed by numerous examples; to which are added rules for Shading, Shade-lining, etc., together with practical instructions as to the Lining, Colouring, Printing, and general treatment of Engineering Drawings, with a chapter on drawing Instruments. By GEORGE S. CLARKE, Capt. R.E. Second edition, *with* 21 *plates*. 2 vols., cloth, 10*s*. 6*d*.

**Engineers' Tables.**—*A Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers.* By Sir GUILFORD L. MOLESWORTH, Mem. Inst. C.E., and R. B. MOLESWORTH. *With numerous illustrations*, 782 pp. Twenty-third edition, 32mo, roan, 6*s*.

SYNOPSIS OF CONTENTS:

Surveying, Levelling, etc.—Strength and Weight of Materials—Earthwork, Brickwork, Masonry, Arches, etc.—Struts, Columns, Beams, and Trusses—Flooring, Roofing, and Roof Trusses—Girders, Bridges, etc.—Railways and Roads—Hydraulic Formulæ—Canals, Sewers, Waterworks, Docks—Irrigation and Breakwaters—Gas, Ventilation, and Warming—Heat, Light, Colour, and Sound—Gravity: Centres, Forces, and Powers—Millwork, Teeth of Wheels, Shafting, etc.—Workshop Recipes—Sundry Machinery—Animal Power—Steam and the Steam Engine—Water-power, Water-wheels, Turbines, etc.—Wind and Windmills—Steam Navigation, Ship Building, Tonnage, etc.—Gunnery, Projectiles, etc.—Weights, Measures, and Money—Trigonometry, Conic Sections, and Curves—Telegraphy—Mensuration—Tables of Areas and Circumference, and Arcs of Circles—Logarithms, Square and Cube Roots, Powers—Reciprocals, etc.—Useful Numbers—Differential and Integral Calculus—Algebraic Signs—Telegraphic Construction and Formulæ.

**Engineers' Tables.**—*Spons' Tables and Memoranda for Engineers.* By J. T. HURST, C.E. Twelfth edition, revised and considerably enlarged, in waistcoat-pocket size (2¾ in. by 2 in.), roan, gilt edges, 1*s*.

**Experimental Science.**—*Experimental Science:* Elementary, Practical, and Experimental Physics. By GEO. M. HOPKINS. *Illustrated by* 890 *engravings*. 840 pp., 8vo, cloth, 16*s*.

**Factories.**—*Our Factories, Workshops, and Warehouses:* their Sanitary and Fire-Resisting Arrangements. By B. H. THWAITE, Assoc. Mem. Inst. C.E. *With* 183 *wood engravings*, crown 8vo, cloth, 9*s*.

**Fermentation.**—*Practical Studies in Fermentation*, being contributions to the Life History of Micro-Organisms. By EMIL CH. HANSEN, Ph.D. Translated by ALEX. K. MILLER, Ph.D., Manchester, and revised by the Author. *With numerous illustrations*, 8vo, cloth, 12*s*. 6*d*.

**Foundations.**—*Notes on Cylinder Bridge Piers and the Well System of Foundations.* By JOHN NEWMAN, Assoc. M. Inst. C.E., 8vo, cloth, 6*s*.

**Founding.**—*A Practical Treatise on Casting and Founding*, including descriptions of the modern machinery employed in the art. By N. E. SPRETSON, Engineer. Fifth edition, with 82 *plates* drawn to scale, 412 pp., demy 8vo, cloth, 18*s.*

**French Polishing.** — *The French - Polisher's Manual.* By a French-Polisher; containing Timber Staining, Washing, Matching, Improving, Painting, Imitations, Directions for Staining, Sizing, Embodying, Smoothing, Spirit Varnishing, French-Polishing, Directions for Repolishing. Third edition, royal 32mo, sewed, 6*d.*

**Furnaces.**—*Practical Hints on the Working and Construction of Regenerator Furnaces*, being an Explanatory Treatise on the System of Gaseous Firing applicable to Retort Settings in Gas Works. By MAURICE GRAHAM, Assoc. Mem. Inst. C.E. *Cuts*, 8vo, cloth, 3*s.*

**Gas Analysis.**—*The Gas Engineers' Laboratory Handbook.* By JOHN HORNBY, F.I.C., Honours Medallist in Gas Manipulation, City and Guilds of London Institute. *Numerous illustrations*, crown 8vo, cloth, 6*s.*

CONTENTS:

The Balance—Weights and Weighing—Sampling—Mechanical Division—Drying and Desiccation — Solution and Evaporation — Precipitation — Filtration and Treatment of Precipitates — Simple Gravimetric Estimations —Volumetric Analyses—Special Analyses required by Gas Works—Technical Gas Analysis—Gas Referees' Instructions, etc. etc.

**Gas Engines.**—*Gas and Petroleum Engines:* a Practical Treatise on the Internal Combustion Engine. By WM. ROBINSON, M.E., Senior Demonstrator and Lecturer on Applied Mechanics, Physics, &c., City and Guilds of London College, Finsbury, Assoc. Mem. Inst. C.E., &c. *Numerous illustrations.* 8vo, cloth.

**Gas Engineering.**—*Manual for Gas Engineering Students.* By D. LEE. 18mo, cloth, 1*s.*

**Gas Works.**—*Gas Works:* their Arrangement, Construction, Plant, and Machinery. By F. COLYER, M. Inst. C.E. *With* 31 *folding plates*, 8vo, cloth, 12*s.* 6*d.*

**Gold Mining.**—*Practical Gold-Mining:* a Comprehensive Treatise on the Origin and Occurrence of Gold-bearing Gravels, Rocks and Ores, and the Methods by which the Gold is extracted. By C. G. WARNFORD LOCK, co-Author of 'Gold: its Occurrence and Extraction.' *With* 8 *plates and* 275 *engravings in the text*, 788 pp., royal 8vo, cloth, 2*l.* 2*s.*

**Graphic Statics.**—*The Elements of Graphic Statics.* By Professor KARL VON OTT, translated from the German by G. S. CLARKE, Capt. R.E., Instructor in Mechanical Drawing, Royal Indian Engineering College. *With* 93 *illustrations*, crown 8vo, cloth, 5*s.*

**Graphic Statics.**—*The Principles of Graphic Statics.* By GEORGE SYDENHAM CLARKE, Capt. Royal Engineers. *With* 112 *illustrations.* Second edition, 4to, cloth, 12*s.* 6*d.*

**Graphic Statics.**—*A New Method of Graphic Statics,* applied in the construction of Wrought-Iron Girders, practically illustrated by a series of Working Drawings of modern type. By EDMUND OLANDER, of the Great Western Railway, Assoc. Mem. Inst. C.E. Small folio, cloth, 10*s.* 6*d.*

**Heat Engine.**—*Theory and Construction of a Natural Heat Motor.* Translated from the German of RUDOLF DIESEL by BRYAN DONKIN, Mem. Inst. C.E. *Numerous cuts and plates,* 8vo, cloth, 6*s.*

**Hot Water.**—*Hot Water Supply:* a Practical Treatise upon the Fitting of Circulating Apparatus in connection with Kitchen Range and other Boilers, to supply Hot Water for Domestic and General Purposes. With a Chapter upon Estimating. By F. DYE. *With illustrations,* crown 8vo, cloth, 3*s.*

**Hot Water.**—*Hot Water Apparatus:* an Elementary Guide for the Fitting and Fixing of Boilers and Apparatus for the Circulation of Hot Water for Heating and for Domestic Supply, and containing a Chapter upon Boilers and Fittings for Steam Cooking. By F. DYE. 32 *illustrations,* fcap. 8vo, cloth, 1*s.* 6*d.*

**Household Manual.**—*Spons' Household Manual:* a Treasury of Domestic Receipts and Guide for Home Management. Demy 8vo, cloth, containing 975 pages and 250 *illustrations,* price 7*s.* 6*d.*

PRINCIPAL CONTENTS:

Hints for selecting a good House—Sanitation—Water Supply—Ventilation and Warming—Lighting—Furniture and Decoration—Thieves and Fire—The Larder—Curing Foods for lengthened Preservation—The Dairy—The Cellar—The Pantry—The Kitchen—Receipts for Dishes—The Housewife's Room—Housekeeping, Marketing—The Dining-Room—The Drawing-Room—The Bedroom—The Nursery—The Sick-Room—The Bath-Room—The Laundry—The School-Room—The Playground—The Work-Room—The Library—The Garden—The Farmyard—Small Motors—Household Law.

**House Hunting.**—*Practical Hints on Taking a House.* By H. PERCY BOULNOIS, Mem. Inst. C.E., City Engineer, Liverpool, Author of 'The Municipal and Sanitary Engineer's Handbook,' 'Dirty Dustbins and Sloppy Streets,' &c. 18mo, cloth, 1*s.* 6*d.*

**Hydraulics.**—*Simple Hydraulic Formulæ.* By T. W. STONE, C.E., late Resident District Engineer, Victoria Water Supply. Crown 8vo, cloth, 4*s.*

**Hydraulic Machinery.**—*Hydraulic Steam and Hand-Power Lifting and Pressing Machinery.* By FREDERICK COLYER, M. Inst. C.E., M. Inst. M.E. Second edition, revised and enlarged. *With* 88 *plates,* 8vo, cloth, 28*s.*

**Hydraulic Motors.**—*Water or Hydraulic Motors.* By PHILIP R. BJÖRLING. *With* 206 *illustrations*, crown 8vo, cloth, 9*s*.

CONTENTS :

1. Introduction—2. Hydraulics relating to Water Motors—3. Water-wheels—4. Breast Water-wheels—5. Overshot and High-breast Water-wheels—6. Pelton Water-wheels—7. General Remarks on Water-wheels—8. Turbines—9. Outward-flow Turbines—10. Inward-flow Turbines—11. Mixed-flow Turbines—12. Parallel-flow Turbines—13. Circumferential-flow Turbines—14. Regulation of Turbines—15. Details of Turbines—16. Water-pressure or Hydraulic Engines—17. Reciprocating Water-pressure Engines—18. Rotative Water-pressure Engines—19. Oscillating Water-pressure Engines—20. Rotary Water-pressure Engines—21. General Remarks and Rules for Water-pressure Engines—22. Hydraulic Rams—23. Hydraulic Rams without Air Vessel in Direct Communication with the Drive Pipe—24. Hydraulic Rams with Air Vessel in Direct Communication with the Drive Pipe—25. Hydraulic Pumping Rams—26. Hydraulic Ram Engines—27. Details of Hydraulic Rams—28. Rules, Formulas, and Tables for Hydraulic Rams—29. Measuring Water in a Stream and over a Weir—Index.

**Hydropathic Establishments.**—*The Hydropathic Establishment and its Baths.* By R. O. ALLSOP, Architect. Author of 'The Turkish Bath' *Illustrated with plates and sections*, 8vo, cloth, 5*s*.

CONTENTS :

General Considerations—Requirements of the Hydropathic Establishment—Some existing Institutions—Baths and Treatments and the arrangement of the Bath-House—Vapour Baths and the Russian Bath—The Douche Room and its appliances—Massage and Electrical Treatment—Pulverisation and the Mont Dore Cure—Inhalation and the Pine Cure—The Sun Bath.

**Ice Making.**—*Theoretical and Practical Ammonia Refrigeration*, a work of Reference for Engineers and others employed in the management of Ice and Refrigeration Machinery. By ILTYD L. REDWOOD, Assoc. Mem. Am. Soc. of M.E., Mem. Soc. Chemical Industry. *With* 25 *plates*. Square 16mo, cloth, 4*s*. 6*d*.

**Indicator.**—*Twenty Years with the Indicator.* By THOMAS PRAY, Jun., C.E., M.E., Member of the American Society of Civil Engineers. *With illustrations*, royal 8vo, cloth, 10*s*. 6*d*.

**Indicator.**—*A Treatise on the Richards Steam-Engine Indicator and the Development and Application of Force in the Steam-Engine.* By CHARLES T. PORTER. *With illustrations.* Fourth edition, revised and enlarged, 8vo, cloth, 9*s*.

**Induction Coils.** — *Induction Coils and Coil Making*: a Treatise on the Construction and Working of Shock, Medical and Spark Coils. By F. C. ALLSOP. Second edition, *with* 125 *illustrations*, crown 8vo, cloth, 3*s*. 6*d*.

**Iron.**—*The Mechanical and other Properties of Iron and Steel in connection with their Chemical Composition.* By A. VOSMAER, Engineer. Crown 8vo, cloth, 6*s*.

CONTENTS :

The metallurgical behaviour of Carbon with Iron and Steel, also Manganese—Silicon—Phosphorus — Sulphur—Copper—Chromium — Titanium—Tungsten—Aluminium—Nickel—Cobalt—Arsenic—Analyses of Iron and Steel, &c.

**Iron Manufacture.**—*Roll-Turning for Sections in Steel and Iron*, working drawings for Rails, Sleepers, Girders, Bulbs, Ties, Angles, &c., also Blooming and Cogging for Plates and Billets. By ADAM SPENCER. Second edition, *with* 78 *large plates.* Illustrations of nearly every class of work in this Industry. 4to, cloth, 1*l.* 10*s.*

**Locomotive.**—*The Construction of the Modern Locomotive.* By GEORGE HUGHES, Assistant in the Chief Mechanical Engineer's Department, Lancashire and Yorkshire Railway. *Numerous engravings*, 8vo, cloth, 9*s.*

CONTENTS:

The Boiler—The Foundry—the Use of Steel Castings—Brass Foundry—The Forge—Smithy, including Springs—Coppersmiths' Work—The Machine Shop—Erecting.

**Lime and Cement.**—*A Manual of Lime and Cement*, their treatment and use in construction. By A. H. HEATH. Crown 8vo, cloth, 6*s.*

**Liquid Fuel.**—*Liquid Fuel for Mechanical and Industrial Purposes.* Compiled by E. A. BRAYLEY HODGETTS. *With wood engravings.* 8vo, cloth, 5*s.*

**Machinery Repairs.**—*The Repair and Maintenance of Machinery;* a Handbook of Practical Notes and Memoranda for Engineers and Machinery Users. By T. W. BARBER, C.E, M.E., Author of 'The Engineers' Sketch Book.' *With about* 400 *illustrations*, 8vo, cloth, 10*s.* 6*d.*

CONTENTS:

Steam Boilers—Prime Movers—Wind Motors and Air Engines—Water Motors—Transmission of Power—Hoisting Machinery—Transport—Machine and Hand Tools—Wood Machinery—Pipe Work—Presses—Printing—Repairing Shops and Tools—Laundries.

**Magneto Hand Telephone.**—*The Magneto Hand Telephone.* Its construction, fitting-up, and adaptability to every-day use. By NORMAN HUGHES. *Cuts*, 12mo, cloth, 3*s.* 6*d.*

**Mechanical Engineering.**—*Handbook for Mechanical Engineers.* By HENRY ADAMS, Professor of Engineering at the City of London College, Mem. Inst. C.E., Mem. Inst. M.E., &c. Fourth edition, revised and enlarged. Crown 8vo, cloth, 7*s.* 6*d.*

CONTENTS:

Fundamental Principles of Mechanics—Varieties and Properties of Materials—Strength of Materials and Structures—Pattern Making—Moulding and Founding—Forging, Welding and Riveting—Workshop Tools and General Machinery—Transmission of Power, Friction and Lubrication—Thermodynamics and Steam—Steam Boilers—The Steam Engine—Hydraulic Machinery—Electrical Engineering—Sundry Notes and Tables.

**Mechanical Engineering.**—*The Mechanician:* a Treatise on the Construction and Manipulation of Tools, for the use and instruction of Young Engineers and Scientific Amateurs, comprising the Arts of Blacksmithing and Forging; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them; description of Hand and Machine Processes; Turning and Screw Cutting By CAMERON KNIGHT, Engineer. *Containing* 1147 *illustrations*, and 397 pages of letter-press. Fourth edition, 4to, cloth, 18*s*.

**Mechanical Movements.**—*The Engineers' Sketch-Book of Mechanical Movements, Devices, Appliances, Contrivances, Details employed in the Design and Construction of Machinery for every purpose.* Collected from numerous Sources and from Actual Work. Classified and Arranged for Reference. *Nearly* 2000 *Illustrations.* By T. W. BARBER, Engineer. Third edition, 8vo, cloth, 10*s*. 6*d*.

**Metal Plate Work.**—*Metal Plate Work: its Patterns and their Geometry.* Also Notes on Metals and Rules in Mensuration for the use of Tin, Iron, and Zinc Plate-workers, Coppersmiths, Boiler-makers and Plumbers. By C. T. MILLIS, M.I.M.E. Second edition, considerably enlarged. *With numerous illustrations.* Crown 8vo, cloth, 9*s*.

**Metrical Tables.**—*Metrical Tables.* By Sir G. L. MOLESWORTH, M.I.C.E. 32mo, cloth, 1*s*. 6*d*.

**Mill-Gearing.**—*A Practical Treatise on Mill-Gearing, Wheels, Shafts, Riggers, etc.;* for the use of Engineers. By THOMAS BOX. Third edition, *with* 11 *plates.* Crown 8vo, cloth, 7*s*. 6*d*.

**Mill-Gearing.**—*The Practical Millwright and Engineer's Ready Reckoner;* or Tables for finding the diameter and power of cog-wheels, diameter, weight, and power of shafts, diameter and strength of bolts, etc. By THOMAS DIXON. Fourth edition, 12mo, cloth, 3*s*.

**Miners' Pocket-Book.**—*Miners' Pocket-Book;* a Reference Book for Miners, Mine Surveyors, Geologists, Mineralogists, Millmen, Assayers, Metallurgists, and Metal Merchants all over the world. By C. G. WARNFORD LOCK, author of 'Practical Gold Mining,' 'Mining and Ore-Dressing Machinery,' &c. Second edition, fcap. 8vo, roan, gilt edges, 12*s*. 6*d*.

CONTENTS:

Motive Power—Dams and Reservoirs—Transmitting Power—Weights and Measures—Prospecting—Boring—Drilling—Blasting—Explosives—Shaft Sinking—Pumping—Ventilating—Lighting—Coal Cutting—Hauling and Hoisting—Water Softening—Stamp Batteries—Crushing Rolls—Jordan's Centrifugal Process—River Mining—Ore Dressing—Gold, Silver, Copper Smelting—Treatment of Ores—Coal Cleaning—Mine Surveying—British Rocks—Geological Maps—Mineral Veins—Mining Methods—Coal Seams—Minerals—Precious Stones—Metals and Metallic Ores—Metalliferous Minerals—Assaying—Glossary—List of Useful Books—Index, &c., &c.

**Mining and Ore-Dressing Machinery.**—By C. G. WARNFORD LOCK, Author of 'Practical Gold Mining.' *Numerous illustrations*, super-royal 4to, cloth, 25*s*.

**Mining.**—*Economic Mining; a Practical Handbook for the Miner, the Metallurgist, and the Merchant.* By C. G. WARNFORD LOCK, Mem. Inst. of Mining and Metallurgy, Author of 'Practical Gold Mining.' *With illustrations*, 8vo, cloth, 21*s*.

**Municipal Engineering.**—*The Municipal and Sanitary Engineer's Handbook.* By H. PERCY BOULNOIS, Mem. Inst. C.E., Borough Engineer, Portsmouth. *With numerous illustrations.* Second edition, demy 8vo, cloth, 15*s*.

CONTENTS:

The Appointment and Duties of the Town Surveyor—Traffic—Macadamised Roadways—Steam Rolling—Road Metal and Breaking—Pitched Pavements—Asphalte—Wood Pavements—Footpaths—Kerbs and Gutters—Street Naming and Numbering—Street Lighting—Sewerage—Ventilation of Sewers—Disposal of Sewage—House Drainage—Disinfection—Gas and Water Companies, etc., Breaking up Streets—Improvement of Private Streets—Borrowing Powers—Artizans' and Labourers' Dwellings—Public Conveniences—Scavenging, including Street Cleansing—Watering and the Removing of Snow—Planting Street Trees—Deposit of Plans—Dangerous Buildings—Hoardings—Obstructions—Improving Street Lines—Cellar Openings—Public Pleasure Grounds—Cemeteries—Mortuaries—Cattle and Ordinary Markets—Public Slaughter-houses, etc.—Giving numerous Forms of Notices, Specifications, and General Information upon these and other subjects of great importance to Municipal Engineers and others engaged in Sanitary Work.

**Paints.**—*Pigments, Paint and Painting.* A Practical Book for Practical Men. By GEORGE TERRY. *With illustrations*, crown 8vo, cloth, 7*s*. 6*d*.

**Paper Manufacture.**—*A Text-Book of Paper-Making.* By C. F. CROSS and E. J. BEVAN. *With engravings*, crown 8vo, cloth, 12*s*. 6*d*.

**Perfumery.**—*Perfumes and their Preparation*, containing complete directions for making Handkerchief Perfumes, Smelling Salts, Sachets, Fumigating Pastils, Preparations for the care of the Skin, the Mouth, the Hair, and other Toilet articles, with a detailed description of aromatic substances, their nature, tests of purity, and wholesale manufacture. By G. W. ASKINSON, Dr. Chem. *With* 32 *engravings*, 8vo, cloth, 12*s*. 6*d*.

**Perspective.**—*Perspective, Explained and Illustrated.* By G. S. CLARKE, Capt. R.E. *With illustrations*, 8vo, cloth, 3*s*. 6*d*.

**Phonograph.**—*The Phonograph, and How to Construct it.* With a Chapter on Sound. By W. GILLETT. *With engravings and full working drawings*, crown 8vo, cloth, 5*s*.

**Popular Engineering.**—*Popular Engineering, being interesting and instructive examples in Civil, Mechanical, Electrical, Chemical, Mining, Military and Naval Engineering*, graphically and plainly described, and specially written for those about to enter the Engineering Profession and the Scientific Amateur, with chapters on Perpetual Motion and Engineering Schools and Colleges. By F. DYE. *With* 700 *illustrations*, crown 4to, cloth, 7*s.* 6*d.*

**Plumbing.**—*Plumbing, Drainage, Water Supply and Hot Water Fitting.* By JOHN SMEATON, C.E., M.S.A., R.P., Examiner to the Worshipful Plumbers' Company. *Numerous engravings*, 8vo, cloth, 7*s.* 6*d.*

**Pumping Engines.**—*Practical Handbook on Direct-acting Pumping Engine and Steam Pump Construction.* By PHILIP R. BJÖRLING. *With* 20 *plates*, crown 8vo, cloth, 5*s.*

**Pumps.**—*A Practical Handbook on Pump Construction.* By PHILIP R. BJÖRLING. *Plates*, crown 8vo, cloth, 5*s.*

CONTENTS:

Principle of the action of a Pump—Classification of Pumps—Description of various classes of Pumps—Remarks on designing Pumps—Materials Pumps should be made of for different kinds of Liquids—Description of various classes of Pump-valves—Materials Pump-valves should be made of for different kinds of Liquids—Various Classes of Pump-buckets—On designing Pump-buckets—Various Classes of Pump-pistons—Cup-leathers—Air-vessels—Rules and Formulas, &c., &c.

**Pumps.**—*Pump Details. With* 278 *illustrations.* By PHILIP R. BJÖRLING, author of a Practical Handbook on Pump Construction. Crown 8vo, cloth, 7*s.* 6*d.*

CONTENTS:

Windbores—Foot-valves and Strainers—Clack-pieces, Bucket-door-pieces, and H-pieces Working-barrels and Plunger-cases—Plungers or Rams—Piston and Plunger, Bucket and Plunger, Buckets and Valves—Pump-rods and Spears, Spear-rod Guides, &c.—Valve-swords, Spindles, and Draw-hooks—Set-offs or Off-sets—Pipes, Pipe-joints, and Pipe-stays—Pump-slings—Guide-rods and Guides, Kites, Yokes, and Connecting-rods—L Bobs, T Bobs, Angle or V Bobs, and Balance-beams, Rock-arms, and Fend-off Beams, Cisterns, and Tanks—Minor Details.

**Pumps.**—*Pumps and Pumping Machinery.* By F. COLYER, Mem. Inst. C.E., Mem. Inst. M.E. Part I., second edition, revised and enlarged, *with* 50 *plates*, 8vo, cloth, 1*l.* 8*s.*

CONTENTS:

Three-throw Lift and Well Pumps—Tonkin's Patent "Cornish" Steam Pump—Thornewill and Warham's Steam Pump—Water Valves—Water Meters—Centrifugal Pumping Machinery—Airy and Anderson's Spiral Pumps—Blowing Engines—Air Compressors—Horizontal High-pressure Engines—Horizontal Compound Engines—Reidler Engine—Vertical Compound Pumping Engines—Compound Beam Pumping Engines—Shonheyder's Patent Regulator—Cornish Beam Engines—Worthington High-duty Pumping Engine—Davy's Patent Differential Pumping Engine—Tonkin's Patent Pumping Engine—Lancashire Boiler—Babcock and Wilcox Water-tube Boilers.

Pumps.—*Pumps, Historically, Theoretically, and Practically Considered.* By P. R. BJÖRLING. *With* 156 *illustrations.* Crown 8vo, cloth, 7*s.* 6*d.*

Quantities.—*A Complete Set of Contract Documents for a Country Lodge*, comprising Drawings, Specifications, Dimensions (for quantities), Abstracts, Bill of Quantities, Form of Tender and Contract, with Notes by J. LEANING, printed in facsimile of the original documents, on single sheets fcap., in linen case, 5*s.*

Quantity Surveying.—*Quantity Surveying.* By J. LEANING. With 68 illustrations. Third edition, revised, demy 8vo, cloth, 15*s.*

CONTENTS :

A complete Explanation of the London Practice.
General Instructions.
Order of Taking Off.
Modes of Measurement of the various Trades.
Use and Waste.
Ventilation and Warming.
Credits, with various Examples of Treatment.
Abbreviations.
Squaring the Dimensions.
Abstracting, with Examples in illustration of each Trade.
Billing.
Examples of Preambles to each Trade.
Form for a Bill of Quantities.
Do. Bill of Credits.
Do. Bill for Alternative Estimate.
Restorations and Repairs, and Form of Bill.
Variations before Acceptance of Tender.
Errors in a Builder's Estimate.
Schedule of Prices.
Form of Schedule of Prices.
Analysis of Schedule of Prices.
Adjustment of Accounts.
Form of a Bill of Variations.
Remarks on Specifications.
Prices and Valuation of Work, with Examples and Remarks upon each Trade.
The Law as it affects Quantity Surveyors, with Law Reports.
Taking Off after the Old Method.
Northern Practice.
The General Statement of the Methods recommended by the Manchester Society of Architects for taking Quantities.
Examples of Collections.
Examples of "Taking Off" in each Trade.
Remarks on the Past and Present Methods of Estimating.

Railway Curves.—*Tables for Setting out Curves for Railways, Canals, Roads, etc.*, varying from a radius of five chains to three miles. By A. KENNEDY and R. W. HACKWOOD. *Illustrated*, 32mo, cloth, 2*s.* 6*d.*

Roads.—*The Maintenance of Macadamised Roads.* By T. CODRINGTON, M.I.C.E., F.G.S., General Superintendent of County Roads for South Wales. Second edition, 8vo, cloth, 7*s.* 6*d.*

Scamping Tricks.—*Scamping Tricks and Odd Knowledge occasionally practised upon Public Works*, chronicled from the confessions of some old Practitioners. By JOHN NEWMAN, Assoc. M. Inst. C.E., author of 'Earthwork Slips and Subsidences upon Public Works,' 'Notes on Concrete,' &c. Crown 8vo, cloth, 2*s.* 6*d.*

Screw Cutting.—*Turners' Handbook on Screw Cutting, Coning, etc., etc.*, with Tables, Examples, Gauges, and Formulæ. By WALTER PRICE. Fcap. 8vo, cloth, 1*s.*

**Screw Cutting.**—*Screw Cutting Tables for Engineers and Machinists*, giving the values of the different trains of Wheels required to produce Screws of any pitch, calculated by Lord LINDSAY. Oblong, cloth, 2*s.*

**Screw Cutting.**—*Screw Cutting Tables*, for the use of Mechanical Engineers, showing the proper arrangement of Wheels for cutting the Threads of Screws of any required pitch, with a Table for making the Universal Gas-pipe Threads and Taps. By W. A. MARTIN, Engineer. Second edition, oblong, cloth, 1*s.*

**Slide Valve.**—*A Treatise on a Practical Method of Designing Slide-Valve Gears by Simple Geometrical Construction*, based upon the principles enunciated in Euclid's Elements, and comprising the various forms of Plain Slide-Valve and Expansion Gearing; together with Stephenson's, Gooch's, and Allan's Link-Motions, as applied either to reversing or to variable expansion combinations. By EDWARD J. COWLING WELCH, Mem. Inst. M.E. Crown 8vo, cloth, 6*s.*

**Soap.**—*A Treatise on the Manufacture of Soap and Candles, Lubricants and Glycerine.* By W. LANT CARPENTER, B.A., B.Sc. *With illustrations*, new edition, revised, crown 8vo, 12*s.* 6*d.*

**Stair Building.**—*Practical Stair Building and Handrailing by the Square Section and Falling Line System.* By W. H. WOOD. *Folding plates*, post 4to, cloth, 10*s.* 6*d.*

**Steam Boilers.**—*Steam Boilers, their Management and Working on land and sea.* By JAMES PEATTIE. *With illustrations*, crown 8vo, cloth, 5*s.*

**Steam Engine.**—*A Practical Treatise on the Steam Engine*, containing Plans and Arrangements of Details for Fixed Steam Engines, with Essays on the Principles involved in Design and Construction. By ARTHUR RIGG, Engineer, Member of the Society of Engineers and of the Royal Institution of Great Britain. Demy 4to, *copiously illustrated with woodcuts and* 103 *plates*, in one Volume. Second edition, cloth, 25*s.*

This work is not, in any sense, an elementary treatise, or history of the steam engine, but is intended to describe examples of Fixed Steam Engines without entering into the wide domain of locomotive or marine practice. To this end illustrations will be given of the most recent arrangements of Horizontal, Vertical, Beam, Pumping, Winding, Portable, Semi-portable, Corliss, Allen, Compound, and other similar Engines, by the most eminent Firms in Great Britain and America. The laws relating to the action and precautions to be observed in the construction of the various details, such as Cylinders, Pistons, Piston-rods, Connecting-rods, Cross-heads, Motion-blocks, Eccentrics, Simple, Expansion, Balanced, and Equilibrium Slide-valves, and Valve-gearing will be minutely dealt with. In this connection will be found articles upon the Velocity of Reciprocating Parts and the Mode of Applying the Indicator, Heat and Expansion of Steam Governors, and the like. It is the writer's desire to draw illustrations from every possible source, and give only those rules that present practice deems correct.

**Steam Engine.**—*The Steam Engine considered as a Thermodynamic Machine*, a treatise on the Thermodynamic efficiency of Steam Engines, illustrated by Tables, Diagrams, and Examples from Practice. By JAS. H. COTTERILL, M.A., F.R.S., Professor of Applied Mechanics in the Royal Naval College. Third edition, revised and enlarged, 8vo, cloth, 15*s*.

**Steam Engine.**—*Steam Engine Management;* a Treatise on the Working and Management of Steam Boilers. By F. COLYER, M. Inst. C.E., Mem. Inst. M.E. New edition, 18mo, cloth, 3*s*. 6*d*.

**Steam Engine.**—*A Treatise on Modern Steam Engines and Boilers*, including Land, Locomotive and Marine Engines and Boilers, for the use of Students. By FREDERICK COLYER, M. Inst. C.E., Mem. Inst. M.E. *With* 36 *plates*. 4to, cloth, 12*s*. 6*d*.

CONTENTS:

1. Introduction—2. Original Engines—3. Boilers—4. High-Pressure Beam Engines—5. Cornish Beam Engines—6. Horizontal Engines—7. Oscillating Engines—8. Vertical High-Pressure Engines—9. Special Engines—11. Portable Engines—11. Locomotive Engines—12. Marine Engines.

**Sugar.**—*Tables for the Quantitative Estimation of the Sugars*, with Explanatory Notes. By Dr. ERNEST WEIN; translated, with additions, by WILLIAM FEW, Ph.D. Crown 8vo, cloth, 6*s*.

**Sugar.**—*A Handbook for Planters and Refiners;* being a comprehensive Treatise on the Culture of Sugar-yielding Plants, and on the Manufacture, Refining, and Analysis of Cane, Palm, Maple, Melon, Beet, Sorghum, Milk, and Starch Sugars; with copious Statistics of their Production and Commerce, and a chapter on the Distillation of Rum. By C. G. WARNFORD LOCK, F.L.S., &c.; B. E. R. NEWLANDS, F.C.S., F.I.C., Mem. Council Soc. Chemical Industry; and J. A. R. NEWLANDS, F.C.S., F.I.C. *Upwards of* 200 *illustrations and many plates*, 8vo, cloth, 1*l*. 10*s*.

**Surveying.**—*A Practical Treatise on the Science of Land and Engineering Surveying, Levelling, Estimating Quantities, etc.*, with a general description of the several Instruments required for Surveying, Levelling, Plotting, etc. By H. S. MERRETT. Fourth edition, revised by G. W. USILL, Assoc. Mem. Inst. C.E. 41 *plates, with illustrations and tables*, royal 8vo, cloth, 12*s*. 6*d*.

**Surveying and Levelling.** — *Surveying and Levelling Instruments theoretically and practically described*, for construction, qualities, selection, preservation, adjustments, and uses, with other apparatus and appliances used by Civil Engineers and Surveyors. By W. F. STANLEY. Second edition. 350 *cuts*, crown 8vo, cloth, 7*s*. 6*d*.

**Tables of Logarithms.**—*A B C Five-Figure Logarithms for general use.* By C. J. WOODWARD, B.Sc. Containing Mantissæ of numbers to 10,000. Log. Sines, Tangents, Cotangents, and Cosines to 10″ of Arc. Together with full explanations and simple exercises showing use of the tables. 4*s.*

**Tables of Squares.**—*Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, Reciprocals of all Integer Numbers up to* 10,000. Post 8vo, cloth, 6*s.*

**Telephones.**—*Telephones, their Construction and Fitting.* By F. C. ALLSOP. Second edition, revised and enlarged. *With* 210 *illustrations.* Crown 8vo, cloth, 5*s.*

**Tobacco Cultivation.**—*Tobacco Growing, Curing, and Manufacturing;* a Handbook for Planters in all parts of the world. Edited by C. G. WARNFORD LOCK, F.L.S. *With illustrations.* Crown 8vo, cloth, 7*s.* 6*d.*

**Tropical Agriculture.**—*Tropical Agriculture:* a Treatise on the Culture, Preparation, Commerce and Consumption of the principal Products of the Vegetable Kingdom. By P. L. SIMMONDS, F.L.S., F.R.C.I. New edition, revised and enlarged, 8vo, cloth, 21*s.*

**Turning.**—*The Practice of Hand Turning in Wood, Ivory, Shell, etc.*, with Instructions for Turning such Work in Metal as may be required in the Practice of Turning in Wood, Ivory, etc.; also an Appendix on Ornamental Turning. (A book for beginners.) By FRANCIS CAMPIN. Third edition, *with wood engravings*, crown 8vo, cloth, 3*s.* 6*d.*

**Valve Gears.**—*Treatise on Valve-Gears*, with special consideration of the Link-Motions of Locomotive Engines. By Dr. GUSTAV ZEUNER, Professor of Applied Mechanics at the Confederated Polytechnikum of Zurich. Translated from the Fourth German Edition, by Professor J. F. KLEIN, Lehigh University, Bethlehem, Pa. *Illustrated*, 8vo, cloth, 12*s.* 6*d.*

**Varnish.**—*The practical Polish and Varnish-Maker;* a Treatise containing 750 practical Receipts and Formulæ for the Manufacture of Polishes, Lacquers, Varnishes, and Japans of all kinds, for workers in Wood and Metal, and directions for using same. By H. C. STANDAGE (Practical Chemist), author of 'The Artist's Manual of Pigments.' Crown 8vo, cloth, 6*s.*

**Ventilation.**—*Health and Comfort in House Building;* or, Ventilation with Warm Air by Self-acting Suction Power. With Review of the Mode of Calculating the Draught in Hot-air Flues, and with some Actual Experiments by J. DRYSDALE, M.D., and J. W. HAYWARD, M.D. *With plates and woodcuts.* Third edition, with some New Sections, and the whole carefully revised, 8vo, cloth, 7*s.* 6*d.*

**Warming and Ventilating.** — *A Practical Treatise upon Warming Buildings by Hot Water*, and upon Heat and Heating Appliances in general; with an inquiry respecting Ventilation, the cause and action of Draughts in Chimneys and Flues, and the laws relating to Combustion. By CHARLES HOOD, F.R.S. Re-written by FREDERICK DYE. Third edition. 8vo, cloth, 15*s.*

**Watchwork.**—*Treatise on Watchwork, Past and Present.* By the Rev. H. L. NELTHROPP, M.A., F.S.A. *With* 32 *illustrations*, crown 8vo, cloth, 6*s.* 6*d.*

CONTENTS:

Definitions of Words and Terms used in Watchwork—Tools—Time—Historical Summary—On Calculations of the Numbers for Wheels and Pinions; their Proportional Sizes, Trains, etc.—Of Dial Wheels, or Motion Work—Length of Time of Going without Winding up—The Verge—The Horizontal—The Duplex—The Lever—The Chronometer—Repeating Watches—Keyless Watches—The Pendulum, or Spiral Spring—Compensation—Jewelling of Pivot Holes—Clerkenwell—Fallacies of the Trade—Incapacity of Workmen—How to Choose and Use a Watch, etc.

**Water Softening.**—*Water Softening and Purification:* the Softening and Clarification of Hard and Dirty Waters. By HAROLD COLLET. Crown 8vo, cloth, 5*s.*

**Waterworks.** — *The Principles of Waterworks Engineering.* By J. H. TUDSBERY TURNER, B.Sc., Hunter Medallist of Glasgow University, M. Inst. C.E., and A. W. BRIGHTMORE, M.Sc., Assoc. M. Inst. C.E. *With illustrations*, medium 8vo, cloth, 25*s.*

**Well Sinking.**—*Well Sinking.* The modern practice of Sinking and Boring Wells, with geological considerations and examples of Wells. By ERNEST SPON, Assoc. Mem. Inst. C.E. Second edition, revised and enlarged. Crown 8vo, cloth, 10*s.* 6*d.*

**Wiring.** — *Incandescent Wiring Hand-Book.* By F. B. BADT, late 1st Lieut. Royal Prussian Artillery. *With* 41 *illustrations and* 5 *tables.* 18mo, cloth, 4*s.* 6*d.*

**Wood-working Factories.**—*On the Arrangement, Care, and Operation of Wood-working Factories and Machinery*, forming a complete Operator's Handbook. By J. RICHARD, Mechanical Engineer. Second edition, revised, *woodcuts*, crown 8vo, cloth, 5*s.*

# SPONS' DICTIONARY OF ENGINEERING,

## CIVIL, MECHANICAL, MILITARY, & NAVAL,

WITH

## Technical Terms in French, German, Italian, and Spanish.

In 97 numbers, Super-royal 8vo, containing 3132 *printed pages* and 7414 *engravings*. **Any number can be had separate:** Nos. 1 to 95 1*s.* each, post free; Nos. 96, 97, 2*s.*, post free.

COMPLETE LIST OF ALL THE SUBJECTS:

In demy 4to, handsomely bound in cloth, *illustrated with* 220 *full page plates*, Price 15*s*.

# ARCHITECTURAL EXAMPLES

## IN BRICK, STONE, WOOD, AND IRON.

### A COMPLETE WORK ON THE DETAILS AND ARRANGEMENT OF BUILDING CONSTRUCTION AND DESIGN.

BY WILLIAM FULLERTON, ARCHITECT.

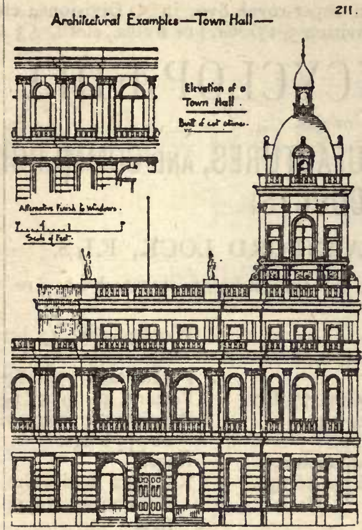
**Containing 220 Plates, with numerous Drawings selected from the Architecture of Former and Present Times.**

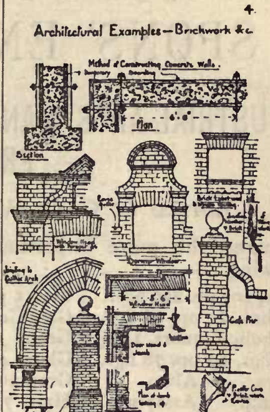
*The Details and Designs are Drawn to Scale, $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{1}{2}''$, and Full size being chiefly used.*

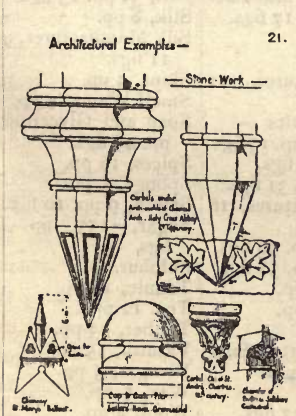
The Plates are arranged in Two Parts. The First Part contains Details of Work in the four principal Building materials, the following being a few of the subjects in this Part:—Various forms of Doors and Windows, Wood and Iron Roofs, Half Timber Work, Porches, Towers, Spires, Belfries, Flying Buttresses, Groining, Carving, Church Fittings, Constructive and Ornamental Iron Work, Classic and Gothic Molds and Ornament, Foliation Natural and Conventional, Stained Glass, Coloured Decoration, a Section to Scale of the Great Pyramid, Grecian and Roman Work, Continental and English Gothic, Pile Foundations, Chimney Shafts according to the regulations of the London County Council, Board Schools. The Second Part consists of Drawings of Plans and Elevations of Buildings, arranged under the following heads:—Workmen's Cottages and Dwellings, Cottage Residences and Dwelling Houses, Shops, Factories, Warehouses, Schools, Churches and Chapels, Public Buildings, Hotels and Taverns, and Buildings of a general character.

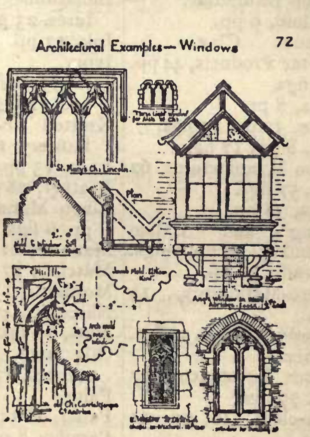
All the Plates are accompanied with particulars of the Work, with Explanatory Notes and Dimensions of the various parts.

*Specimen Pages, reduced from the originals.*



*With nearly* 1500 *illustrations*, in super-royal 8vo, in 5 Divisions, cloth. Divisions 1 to 4, 13*s.* 6*d.* each; Division 5, 17*s.* 6*d.*; or 2 vols., cloth, £3 10*s.*

# SPONS' ENCYCLOPÆDIA

OF THE

## INDUSTRIAL ARTS, MANUFACTURES, AND COMMERCIAL PRODUCTS.

EDITED BY C. G. WARNFORD LOCK, F.L.S.

Among the more important of the subjects treated of, are the following:—

Acids, 207 pp. 220 figs.
Alcohol, 23 pp. 16 figs.
Alcoholic Liquors, 13 pp.
Alkalies, 89 pp. 78 figs.
Alloys. Alum.
Asphalt. Assaying.
Beverages, 89 pp. 29 figs.
Blacks.
Bleaching Powder, 15 pp.
Bleaching, 51 pp. 48 figs.
Candles, 18 pp. 9 figs.
Carbon Bisulphide.
Celluloid, 9 pp.
Cements. Clay.
Coal-tar Products, 44 pp. 14 figs.
Cocoa, 8 pp.
Coffee, 32 pp. 13 figs.
Cork, 8 pp. 17 figs.
Cotton Manufactures, 62 pp. 57 figs.
Drugs, 38 pp.
Dyeing and Calico Printing, 28 pp. 9 figs.
Dyestuffs, 16 pp.
Electro-Metallurgy, 13 pp.
Explosives, 22 pp. 33 figs.
Feathers.
Fibrous Substances, 92 pp. 79 figs.
Floor-cloth, 16 pp. 21 figs.
Food Preservation, 8 pp.
Fruit, 8 pp.
Fur, 5 pp.
Gas, Coal, 8 pp.
Gems.
Glass, 45 pp. 77 figs.
Graphite, 7 pp.
Hair, 7 pp.
Hair Manufactures.
Hats, 26 pp. 26 figs.
Honey. Hops.
Horn.
Ice, 10 pp. 14 figs.
Indiarubber Manufactures, 23 pp. 17 figs.
Ink, 17 pp.
Ivory.
Jute Manufactures, 11 pp., 11 figs.
Knitted Fabrics — Hosiery, 15 pp. 13 figs.
Lace, 13 pp. 9 figs.
Leather, 28 pp. 31 figs.
Linen Manufactures, 16 pp. 6 figs.
Manures, 21 pp. 30 figs.
Matches, 17 pp. 38 figs.
Mordants, 13 pp.
Narcotics, 47 pp.
Nuts, 10 pp.
Oils and Fatty Substances, 125 pp.
Paint.
Paper, 26 pp. 23 figs.
Paraffin, 8 pp. 6 figs.
Pearl and Coral, 8 pp.
Perfumes, 10 pp.
Photography, 13 pp. 20 figs.
Pigments, 9 pp. 6 figs.
Pottery, 46 pp. 57 figs.
Printing and Engraving, 20 pp. 8 figs.
Rags.
Resinous and Gummy Substances, 75 pp. 16 figs.
Rope, 16 pp. 17 figs.
Salt, 31 pp. 23 figs.
Silk, 8 pp.
Silk Manufactures, 9 pp. 11 figs.
Skins, 5 pp.
Small Wares, 4 pp.
Soap and Glycerine, 39 pp. 45 figs.
Spices, 16 pp.
Sponge, 5 pp.
Starch, 9 pp. 10 figs.
Sugar, 155 pp. 134 figs.
Sulphur.
Tannin, 18 pp.
Tea, 12 pp.
Timber, 13 pp.
Varnish, 15 pp.
Vinegar, 5 pp.
Wax, 5 pp.
Wool, 2 pp.
Woollen Manufactures, 58 pp. 39 figs.

Crown 8vo, cloth, 485 pages, with illustrations, 5*s.*

# WORKSHOP RECEIPTS,

## SECOND SERIES.

SYNOPSIS OF CONTENTS.

Acidimetry and Alkalimetry.
Albumen.
Alcohol.
Alkaloids.
Baking-powders.
Bitters.
Bleaching.
Boiler Incrustations.
Cements and Lutes.
Cleansing..
Confectionery.
Copying.
Disinfectants.
Dyeing, Staining, and Colouring.
Essences.
Extracts.
Fireproofing.
Gelatine, Glue, and Size.
Glycerine.
Gut.
Hydrogen peroxide.
Ink.
Iodine.
Iodoform.
Isinglass.
Ivory substitutes.
Leather.
Luminous bodies.
Magnesia.
Matches.
Paper.
Parchment.
Perchloric acid.
Potassium oxalate.
Preserving.

**Pigments, Paint, and Painting:** embracing the preparation of *Pigments*, including alumina lakes, blacks (animal, bone, Frankfort, ivory, lamp, sight, soot), blues (antimony, Antwerp, cobalt, cæruleum, Egyptian, manganate, Paris, Péligot, Prussian, smalt, ultramarine), browns (bistre, hinau, sepia, sienna, umber, Vandyke), greens (baryta, Brighton, Brunswick, chrome, cobalt, Douglas, emerald, manganese, mitis, mountain, Prussian, sap, Scheele's, Schweinfurth, titanium, verdigris, zinc), reds (Brazilwood lake, carminated lake, carmine, Cassius purple, cobalt pink, cochineal lake, colcothar, Indian red, madder lake, red chalk, red lead, vermilion), whites (alum, baryta, Chinese, lead sulphate, white lead—by American, Dutch, French, German, Kremnitz, and Pattinson processes, precautions in making, and composition of commercial samples—whiting, Wilkinson's white, zinc white), yellows (chrome, gamboge, Naples, orpiment, realgar, yellow lakes); *Paint* (vehicles, testing oils, driers, grinding, storing, applying, priming, drying, filling, coats, brushes, surface, water-colours, removing smell, discoloration; miscellaneous paints—cement paint for carton-pierre, copper paint, gold paint, iron paint, lime paints, silicated paints, steatite paint, transparent paints, tungsten paints, window paint, zinc paints); *Painting* (general instructions, proportions of ingredients, measuring paint work; carriage painting—priming paint, best putty, finishing colour, cause of cracking, mixing the paints, oils, driers, and colours, varnishing, importance of washing vehicles, re-varnishing, how to dry paint; woodwork painting).

# WORKSHOP RECEIPTS,

## FOURTH SERIES,

## DEVOTED MAINLY TO HANDICRAFTS & MECHANICAL SUBJECTS.

**250 Illustrations, with Complete Index, and a General Index to the Four Series, 5s.**

---

**Waterproofing** — rubber goods, cuprammonium processes, miscellaneous preparations.

**Packing and Storing** articles of delicate odour or colour, of a deliquescent character, liable to ignition, apt to suffer from insects or damp, or easily broken.

**Embalming and Preserving** anatomical specimens.

**Leather Polishes.**

**Cooling Air and Water,** producing low temperatures, making ice, cooling syrups and solutions, and separating salts from liquors by refrigeration.

**Pumps and Siphons,** embracing every useful contrivance for raising and supplying water on a moderate scale, and moving corrosive, tenacious, and other liquids.

**Desiccating**—air- and water-ovens, and other appliances for drying natural and artificial products.

**Distilling**—water, tinctures, extracts, pharmaceutical preparations, essences, perfumes, and alcoholic liquids.

**Emulsifying** as required by pharmacists and photographers.

**Evaporating**—saline and other solutions, and liquids demanding special precautions.

**Filtering**—water, and solutions of various kinds.

**Percolating and Macerating.**

**Electrotyping.**

**Stereotyping** by both plaster and paper processes.

**Bookbinding** in all its details.

**Straw Plaiting** and the fabrication of baskets, matting, etc.

**Musical Instruments**—the preservation, tuning, and repair of pianos, harmoniums, musical boxes, etc.

**Clock and Watch Mending**—adapted for intelligent amateurs.

**Photography**—recent development in rapid processes, handy apparatus, numerous recipes for sensitizing and developing solutions, and applications to modern illustrative purposes.

In demy 8vo, cloth, 600 pages and 1420 illustrations, **6s.**

FOURTH EDITION.

# SPONS' MECHANICS' OWN BOOK;

## A MANUAL FOR HANDICRAFTSMEN AND AMATEURS.

CONTENTS.

Mechanical Drawing—Casting and Founding in Iron, Brass, Bronze, and other Alloys—Forging and Finishing Iron—Sheetmetal Working—Soldering, Brazing, and Burning—Carpentry and Joinery, embracing descriptions of some 400 Woods, over 200 Illustrations of Tools and their uses, Explanations (with Diagrams) of 116 joints and hinges, and Details of Construction of Workshop appliances, rough furniture, Garden and Yard Erections, and House Building—Cabinet-Making and Veneering — Carving and Fretcutting — Upholstery — Painting, Graining, and Marbling — Staining Furniture, Woods, Floors, and Fittings—Gilding, dead and bright, on various grounds—Polishing Marble, Metals, and Wood—Varnishing—Mechanical movements, illustrating contrivances for transmitting motion—Turning in Wood and Metals—Masonry, embracing Stonework, Brickwork, Terracotta and Concrete—Roofing with Thatch, Tiles, Slates, Felt, Zinc, &c.—Glazing with and without putty, and lead glazing—Plastering and Whitewashing — Paper-hanging — Gas-fitting—Bell-hanging, ordinary and electric Systems — Lighting — Warming — Ventilating — Roads, Pavements, and Bridges — Hedges, Ditches, and Drains — Water Supply and Sanitation—Hints on House Construction suited to new countries.



LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

3

N

I
anc
—S
des
the
De
Ga
and
Gra
Fitt
Ma
illus
and
and
Gla
Whi
and
Pav
Sup
coun

E.

L